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Integration Of Building Information & Internet Of Things For Smart Construction Management

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ABSTRACT

Sustainable development, which has become the priority study of architectural design, is receiving increasing attention with global climate change. At the same time, the building industry is urgently changing towards intelligent and digitalized tendencies. As a result, Building Information Modeling (BIM) and the Internet of Things (IoT) make crucial contributions to the transforming process. However, there is little knowledge of the integration of BIM–IoT in sustainable building from a macro perspective. Moreover, most existing research adopts a literature review method and lacks objective quantitative analysis. Controlled terms and subject terms statistics from the Engineering Index core database search results are also used to briefly examine the research frontiers and hotspots as obtained from Cite space. The results show that: (1) The research on BIM–IoT integration focuses on building intelligence with BIM as the basis of application, and research on BIM–IoT integration within the field of sustainable building is currently focused on the first three phases of the life cycle. (2) The development of sustainable buildings needs to be considered on its human and social dimensions. BIM provides a platform for sharing information and communication among stakeholders involved in the building's entire life cycle. At the same time, IoT allows occupants to better participate in buildings' sustainable design and decision making. (3) In the future, more emerging technologies such as cloud computing and big data are required to better promote sustainable buildings and thus realize the construction of sustainable smart cities. At the same time, researchers should also pay attention to the sustainable transformation of existing buildings.

Keywords: Building Information Modeling (BIM); Internet of Things (IoT); sustainable building; smart cities; information management; building metaverse; life cycle.

1. INTRODUCTION

The development of smart construction requires the deployment of innovative methods, tools and approaches. Internet of Things (hereinafter referred to as IoT) represents functional (objects worldwide can exchange information through the internet) as well as technical (identification, data collection and processing capabilities) perspectives and can be applied variably e.g., for monitoring and intelligent management processes [Chen, Fengchen, et al].

The operational phase has the highest percentage (80–85%) of energy consumption in the building life cycle [Sharma, Aashish, et al]. At this stage, it is important to plan the building maintenance and timely repairs to prevent the premature end of its life cycle. Finally, the liquidation phase is carried out in case of deterioration of the physical condition of the building when reconstruction is no longer possible. If a demolition decision is made, the life cycle of the building ends. An important point in demolition works is the management of construction waste [König, Holger, and M. Lisa De Cristofaro].

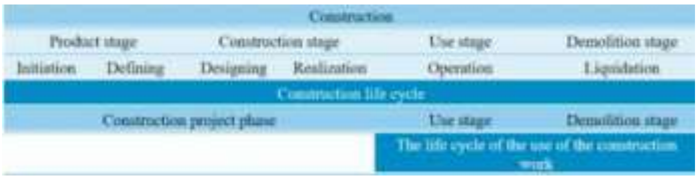

Figure 1.1: Main building life-cycle phases, based on [Leśniak, Agnieszka, Kuda, František et.al].

The above-mentioned description of individual building life-cycle phases (see Figure) indicates that the deployment of IoT might be different for individual phases. This work builds on the existing research on the topic of the possibilities of IoT use within the construction industry from the life-cycle perspective. Emphasis is placed on the analysis of the IoT use in two major phases of the construction facilities' life cycle, i.e., construction and operational phases. The aim of this study is to provide an actual overview, key terminology and possible ways of the IoT usage based on reliable sources with emphasis on the application examples.

(Antonino Mannino et.al) The construction industry has a relatively low digitisation level compared to other sectors [Haghsheno, S.; Deubel et.al, Hossain, M.A.; Nadeem, A et.al]. Although it is seen as a major factor in the innovation of the Architecture, Engineering and Construction and Operations (AECO) sector, digitisation in the construction industry still shows a slow growth rate [Oesterreich, T.D.; Teuteberg, F et al]. However, improvements in methodologies and technologies are under development to better manage AECO processes [Blanco, J.; Mullin et al]. This article presents a literature review on the integration of Building Information Modelling (BIM) and Internet of Things (IoT) for the Facility Management (FM) of the constructed asset. It is divided into four main parts: (a) an overview of FM and the impact of digitisation in the sector; (b) the description of the research method; (c) an in-depth content analysis of 99 selected journals' articles on BIM-IOT integration for FM, which allows identifying both benefits/opportunities and issues/limits at technical and operational levels; (d) conclusions and a description of a possible future research agenda. The context is the fourth industrial revolution (Industry 4.0), where several technological changes in many sectors have been made, including in the AECO one [McKinsey Global Institute, Chung, S.W.; Kwon et al]. There are many studies on the application of digital technologies aiming to promote digitisation in the built environment. However, compared to the design and construction stages, there is a lack of research on applying these new technologies in the operation and use stage of the building life cycle [Wong, J.K.W et al], particularly for the FM sector. FM represents up to 85% of the whole life cycle cost of the building [Cheng, J.C.P.; Chen et al]. Even though the life cycle cost of a building can and should be controlled in the design phase the adoption of innovative tools and technologies to improve FM in existing buildings is continually increasing. Wong et al. [Wong, J.K.W et al] identified and discussed several possibilities for future research into digital technologies like integrating FM with BIM, reality capture technology, IoT, Radio Frequency Identification (RFID), and Geographic Information System. Among several studies on applying new technologies, a significant solution taken into consideration in the last years by the AECO sector has emerged: the Cyber-Physical Systems (CPS) [Chung, S.W.; Kwon et al]. CPS, also known as Digital Twins (DT), are systems based on the combination of physical and digital objects. Through simulation of an as-built component (or system), using digital models and several types of data, DT allows mirroring the life of its corresponding real twin to forecast the health of building components, their service life, faults [Glaessgen, E.; Stargel et al] and, in general, the building performances [Bonci, A.; Carbonari et al]. Even if not risk-free, these digital innovations will enable new dynamics and allow new services that will improve efficiency and sustainability in building management processes [Love, P.E.D.; et al].

1.2 Facility Management

Facility management is a multidisciplinary topic that requires the collaboration and coordination of different people [Chung, S.W.; Kwon et al]. ISO 41011:2017 defines FM as an "organisational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business" [ISO 41011:2017]. According to International Facility Management Association (IFMA), there are 11 core competencies in FM [International Facility Management Association (IFMA)]: Occupancy and Human

Factors, Operations and Maintenance (O&M), Sustainability, Facility Information and Technology Management, Risk Management, Communication, Performance and Quality, Leadership and Strategy, Real Estate, Project Management, Finance and Business. Currently, not all buildings have optimal management [Omar, N.S.; Najy, Vanier, D.J.] due to outdated procedures that cause a lack of data and information. In other cases, despite the use of sensors/automatic devices and databases, the information collected is not entirely exploited [Cheng, J.C.P.; Chen et al]. An example is given by FM information systems, e.g., Computerised Maintenance Management Systems (CMMS), Energy Management Systems (EMS) and Building Automation Systems (BAS), where data are often fragmented and manually entered after the handover of the building. Fragmentation and data poorness could generate laborious and inefficient processes [Wong, J.K.W et al]. Furthermore, FM operators often rely on paper documents in their daily activities. This increases both the time needed and the difficulties of getting accurate information [Xiao, Y.-Q. et al]. For these reasons, the improvement of both FM tools and processes is a crucial issue in FM companies [Wanigarathna, N et al]. Hence, with increasing industry interest, a review of the current status and a description of a future research agenda on FM is needed.

1.2.1 Digitisation and FM

New technologies have transformed many people's daily lives and have revolutionized several traditional industry practices aiming to achieve efficiency, accuracy, and precision. This evolution has gained momentum due to advancements in technologies such as the Internet of Things (IoT), big data, cloud computing and cyber-physical systems [Rajput, S.; Singh et al].

The strengths of these innovations 4.0 lie in monitoring, controlling, interoperability, real-time information processing and process self-optimization [Rajput, S.; Singh, et al]. The physical world's connection with the virtual world enables products and components to create a self adapting and self-managing communication network [De Sousa Jabbour et al]. In the construction sector, the first attempt at digitization aiming to increase the sector's efficiency has already been seen with the spread of BIM [Ashworth, S.; Tucker et al].

1.2.2 Building Information Modelling for FM

The United States National Institute of Building Sciences (NIBS) defines BIM as "The digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards" [NIBS]. In recent years, BIM has been more and more employed in the AECO sector to improve information management. BIM Models (BIMs) allow integrated management of information throughout the building's entire life cycle, hence improving FM [Hilal, M.; Maqsood et al]. On the one hand, BIM allows working more efficiently during the design and construction phases by developing a 3D model that avoids project interference and allows project time and cost calculation. On the other hand, it allows acquiring data created during several phases of the building life cycle to use them in operations management, maintenance activities, environmental analysis and energy performance simulations. The latter is related to Building Energy Modelling (BEM), which has become an essential aspect for FM. Benefits of using BIM in FM include providing "as-is" information and enabling Facility Managers to work on information using a single source of data, overcoming all the issues deriving from the sources' fragmentation. A BIM model has different Levels of Information Needs [ISO 19650-2:2018]. To deal with them, the American BIM Forum defined the Level of Development (LOD) Specification. This reference enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process. A BIM model has six Levels Of Development (LOD): LOD 100, LOD 200, LOD 300, LOD 350, LOD 400 and LOD 500 [BIM Forum]. Each LOD defines how much information is included in a building component. The higher the LOD, the greater the clarity and reliability of data and information. According to Love et al. [Love, P.E.D et al], using the highest LOD is possible in order to enrich the digital model with all the information necessary for assets management and maintenance. In this way, data are more efficiently stored in a single file without fragmentation or loss of information. Moreover, improving the handover process is possible using fewer paper documents or manual transfer of information [Love, P.E.D et al]. As early as 2012, Becerik-Gerber et al have defined, also through surveys and interviews, how BIM can support FM practices. Their paper assesses the status of BIM implementations in FM, potential applications, level of interest in BIM utilisation, application areas, and data requirements for BIM-enabled FM practices. To date, studies on BIM application in FM confirm momentum (e.g., [Wanigarathna, N.; Jones et al, Bortoluzzi, B.; Efremov et al, Matarneh, S.T.; Danso-Amoako et al, Wang, Y.; Wang, X.; Wang et al, smail, Z.A et al). However, despite all the advantages, BIM is not often used in the FM phase. The most significant causes that hinder this integration are: (1) Industry perception, which considers BIM models just as 3D models and not as informative models with business value [Munir, M.; Kiviniemi, et al]. (2) Lack of involvement of the facility managers in the creation of the BIM model [Dixit, M.K.; Venkatraj et al]. Consequently, less information useful for FM is integrated into the model. (3) The need for interoperability between BIM and FM technologies and the lack of open systems and standardised data libraries that can be utilised as a bridge between BIM and CAFM technologies [Pärn, E.A.; Edwards, D.J et al]. (4) Lack of clear roles, responsibilities, contract and liability framework [Pärn, E.A.; Edwards, D.J et al]. (5) Furthermore, the main limitation of BIM methodology is its static information: data are provided during the design phase but not updated during the building's life cycle [Patacas, J.; Dawood et al]. This is a relevant issue for buildings management, and research is moving in this direction.

1.3 Internet of Things for FM

Asghari, Rahmani and Javadi define IoT as "an ecosystem that contains smart objects equipped with sensors, networking and processing technologies integrating and working together to provide an environment in which smart services are taken to the end-users". They show how this ecosystem is being applied in healthcare, environmental, smart cities, commercial and industrial contexts. IoT has led to an interconnection between people and objects at an unprecedented scale and pace [Gubbi, J.; Buyya et al] and will allow new strategies to improve quality of life [Pradeep, S.; Kousalya et al]. Furthermore, connected devices could be programmed to make autonomous decisions and adequately inform users to make the best decisions [Rizal, R.; Hikmatyar et al]. Operation and maintenance stages represent 50–70% of the total annual facility operating costs [Rondeau, E.P.; Brown et al], and buildings management requires integrating and analysing different types of data and information generated by various stakeholders. This implies that improved data and information management can have a significant impact on building performance. In this context, the application and integration of IoT and BIM technologies to gather and store data/information for the entire life cycle of the building have caught wide attention. In recent years, a growing number of innovations have been developed [Wong, J.K.W.; Ge et al].

Most of the current studies can only be considered as the integration of BIM and IoT devices that lack information sharing across the Internet through a unified framework. The applications of BIM and IoT device integration are scattered, it is sufficiently matured that patterns, issues, and opportunities can be identified. While the BIM and IoT device integration is still nascent, there is a need to understand the current situation of BIM and IoT device integration including:

- What are the prevalent application domains for BIM and IoT device integration? How to categorize these application domains?
- What are the integration methods for BIM and IoT device?
- What are the limitations for both application domains and integration methods?
- What are the research gaps and fruitful future research directions?

1.4 Building Information Modelling (BIM)

It has become an influential paradigm for the development of better project delivery practices to improve construction and operational efficiencies. BIM projects give high reliability, geometrically, well positioned, and accurate identifiable building components data sets. On the other hand, Internet of Things (IoT) is the interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. Some IoT enabling technologies includes sensing technologies, software and cloud platforms, position technologies, and so on. The integration of BIM with IoT devices is vital for applications and is a relatively new development. In general, BIM and IoT data offer complementary views of a project, whereby together they enhanced the limitations of each of them. BIM models offer high trustworthiness depictions of a project at the component level. In the last 6 years, with the persistent interest from the research community, a significant number of studies have been published on the integration of BIM in IoT. However, to the best of knowledge, systematic mapping studies in this research domain are non-existent. In this mapping study, we intend to fill this research gap by comprehensively analysing important studies published in the last five years (2015 - 2020). This study will primarily help researchers in identifying the key application domains, validation methods, contribution facets, research types, simulation tools, performance measures, and the general demographics of the selected studies in the field of study.

1.5 Building Information Modelling (BIM) in various field

BIM can be an important component of information management in the AEC sectors by focusing on the need for information management and data interchange between stakeholders throughout the project lifecycle. BIM is a set of procedures that helps enhance the building industry's outputs, relationships, and responsibilities. To facilitate better communication among BIM stakeholders, these deliverables are organized according to the notion of "level of development," a reference tool specifying minimum requirements for the features and details of components in 3D models. Figure 1 shows the different dimensions of BIM. As can be seen in Figure, BIM is broken down into three distinct areas: policy, process, and technology. When these three disciplines work together, a framework emerges for digitally managing building data throughout the design and construction phases. Furthermore, BIM is a new approach to the whole building lifecycle data creation, use, and sharing process. Furthermore, although some claim that BIM can only be used for construction projects, many contend that because the word "building" in BIM refers to the construction process rather than a physical structure, BIM can be applied to civil infrastructure projects to enhance project delivery. Employing BIM in civil infrastructure facilities, such as bridges, tunnels, dams, airports, and railways, is called "civil information modeling" (CIM) in the AEC sector. BIM could be utilized for different purposes in civil infrastructure projects, including visualization, design and modeling, lifecycle information management, structural health analysis, traffic flow simulation, computational fluid dynamics, clash detection, time and cost management, and sustainability.

1.6 Digital Twins (DT)

However, the AEC sector has only lately started using the Digital Twin (DT) technique. The concept of using a twin model dates back to the 1970s when NASA's Apollo program created two identical spacecraft to mirror the circumstances of the spacecraft [40]. The terms "BIM" and "DT" are often used interchangeably. While a DT's key role is to simulate the object it reflects, BIM's primary goal is to produce a 3D extension of a real-world item. It is feasible to interchange data and information with other DT simulators and programs by including data and information throughout the lifecycle of an asset. Technical capabilities (such as software, sensors, and actuators) and a solid comprehension of conceptual support techniques, such as industrial resource management, technology lifecycles, natural resource management, and communication tools, are necessary for the successful operation of a DT. According to research from Cambridge University, a method for using artificial intelligence to make Digital Twins of patients and track their health state has been discovered. Additionally, a DT employs tools and technologies to map the physical thing's stored data, aiding in the production of current knowledge about the physical object. As in cyber-physical systems, it performs via synchronized real-time information coordination between the hardware (physical object) and software (virtual object). To describe the change from BIM to DT, Deng, et al. developed a five-level ladder taxonomy. The stages of BIM include level 1, level 2, assisted simulations, level 3, integration with IoT, level 4, coupled with AI techniques for predictions, and level 5, optimum DT. Based on the building life cycle, each level of the ladder taxonomy was divided into a number of subcategories with a focus on distinct study disciplines allocated to the design, construction, operation, and demolition stages. Developing DT frameworks often involves integrating the Internet of Things (IoT), BIM, and finite element models. These DT frameworks provide updates that are practically real-time to improve construction management.

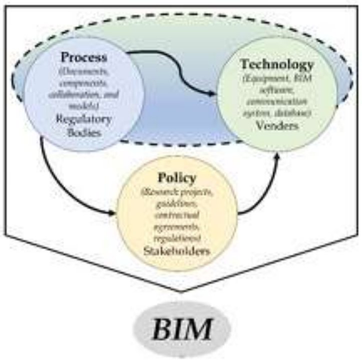

Figure 1.2: The three main fields in BIM

1.7 Objectives of the Present Study

The current increase in necessity of speedy construction, material prices and labour charges, it is becoming difficult for middle class families to fulfill their dream of living in their own homes. The overall aim of this research is to analyze the Use of Integration of building Information and internet of things for smart construction management projects. Speedy and accurate necessity in construction industry, it may be one of the way of reducing construction reducing the time and material management in the construction industry.

The Objectives of the Study is divided in to the following

1. To study different construction projects with respect to BIM and IoT, this includes residential project, infrastructure project and industrial project.
2. To minimize time, cost of construction projects with respect to different factors.
3. To study about Comparative methods by BIM and IoT over with conventional construction projects.
4. To formulate the recommendations to improve the procedure of economical material selection through use of locally available material in construction projects.

1.8 Need for the Study

The Construction projects involve a mainly the financial concerned along with the series of activities to accomplish their goals. The detailed information is infrastructural construction management is important role in construction industry due to various factors not in specific each activity of every levels. The modern BIM and IoT is important role in the construction especially for modern construction method and the material cost of the each activity throughout the construction process. So the study requires Building information modelling and Internet of Things for smart construction management for sustainable construction.

1.9 Scope of the Research

This Research / Study illustrates the BIM and IoT usage of an infrastructure in construction industry. Prior to embarking on any study, it is necessary to define the scope and to plan its implementation in operational terms as if it were a project in its own right. The aim is to provide a clear explicit shared understanding of the process that will be implemented. This study questionnaire covered the area of local markets around Maharashtra only the procedure may help for other locations.

2. LITERATURE REVIEW

2.1 General

The most important problems in the construction industry is managing the accurate prediction and detailing of construction industry. BIM and IoT is every construction project and the magnitude of these delays cost considerably from project to project. So it is essential to define the actual causes of and managing those in any construction project. This chapter discusses about the literature under the following heads: types of economic material, causes of cost risks, resource related factors causing managing, data analysis and inference from literature survey.

2.2 IoT contributions to Industry4.0/Construction 4.0

(Yulia Shvets et al)In this way, IoT contributes to Industry 4.0/Construction 4.0 efforts by providing technologies for effective data sharing and management beneficial to smarter, cheaper, faster and more sustainable production and operation. Available scientific literature provides several definitions of IoT. For example, International Telecommunication Union understands IoT as “A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” [Chen, Fengchen, et al, ITU-T recommendation Y.2060]. IoT is beginning to be widely used within the construction industry which is highly specific for a large resource consumption of material, energy and labour. Furthermore, an important aspect is the long service life of the built structures as well as the high level of complexity of the entire construction project. Therefore, the IoT has a high potential for use within the construction sector from various points of view. When speaking about the long service life of buildings, it is important to study them in their particular phases. The general life cycle of every construction consists of the product stage, construction process stage, use stage and demolition stage.

[Leśniak, Agnieszka] has identified the following stages of the building life cycle as the conceptual analysis and design phase, execution (construction) phase, operational phase and decommissioning phase. It is worth mentioning that each life cycle of a particular facility is specific from various perspectives, such as the set of activities realized or outputs expected. The main aim of the conceptual analysis and design phase is to make the project as efficient as possible. An efficient and smart decision-making process creates less cost in earlier design phases. At this stage, it is easier to make changes to the project. The results of the product stage are the basis for making a decision on the implementation of the investment project, adjusting the investment plan or refusing to implement the project. The following construction stage begins by obtaining a building permit and ends with the commissioning of the facility. An important part of this stage is to ensure that the contractor completes the project according to plan and to carry out the quality control inspections. The total environmental impact of the construction phase is about 11%. [Sharma, Aashish, et al] During the operation phase of the building life cycle, it is being used and related to significant operation and maintenance costs. The operation stage is the longest and most expensive part of the building life cycle [Leśniak, Agnieszka].

(Milad Baghalzadeh Shishehgarkhaneh et al) To address chronic low productivity and unsatisfactory construction project performance, researchers and professionals in the fields of architecture, engineering, and construction (AEC) are looking at alternatives to standard project delivery models and approaches. Failures of integration and collaboration, which are crucial for enhancing and regulating the value stream, have been recognized as a core reason for these performance concerns. The original design assistance tools to assist architects in building design were paper and pen; with the advent of Computer-Aided Design (CAD) tools, architects were able to use digital drawing methods to construct vertical and horizontal lines. In the previous several decades, CAD tool techniques have evolved iteratively, from their early limitation of copying pen and paper to the succeeding provision of numerous computing and linking capabilities. A framework known as “construction 4.0” intends to bring together three major categories: (i) industrial production, (ii) cyber-physical systems, and (iii) digital and computational technologies. Prefabrication and off-site manufacturing are examples of industrial production, and sensors, the Internet of Things (IoT), robotics, and drones are the main emphasis of cyber-physical systems in these processes. Building Information Modeling (BIM), Digital Twin (DT), artificial intelligence (AI), augmented/virtual reality (AR/VR), and cloud computing are examples of digital-computational technology.

Cheun's work (2018) considers the possibility of the integrated usage of IoT and BIM, which can develop construction safety management. The case study involves combining environmental condition data obtained from IoT and their visual display for analysis and control based on the BIM model. The created sensor system was placed on an underground construction site to collect data on the level of dangerous gas and the state of the environment (temperature and humidity). When an abnormal condition is detected, the BIM model starts an alarm, which automatically starts an alert at the construction site [Cheung, Weng-Fong et.al].

Another research made in the field of safety on the construction site was made by Zhou (2017). The safety barrier warning system has been applied in Yangzte river-crossing metro tunnel underground construction site. The system enables data collection to monitor workers and equipment on the site in real time and generate alerts with a high response speed. IoT technologies such as positioning, ultrasonic detection at the centimetre level and infrared access technology were used. This can help workers avoid accidents, as well as improve safety management through work organization and safety planning [Zhou, C., and L. Y. Ding et.al]. The problem of the

IoT implementation was also considered by Woodhead (2018). In this paper, the authors argue that considering the Internet of Things (IoT) in certain narrow areas limits the prospects for possible development. It is proposed to consider IoT in a complex, taking into account the achievement of a fundamentally new level of development for the Smart cities in the field of information technologies, for example, BIM modelling. Due to the complex approach and the possibility of processing a large amount of data, it is possible to increase the efficiency of the decision-making process and project management workflow [Woodhead, Roy, Paul Stephenson et.al].

This complementarity expands the possibilities of processing and perception of information necessary for building management. Nowadays processing a large amount of information has limits and restrictions. Despite this fact, the potential for further development of the interaction between BIM and IoT has been highlighted for the communication, construction and progress monitoring, health and safety, logistics and management, automation, prefabrication, lean construction, FM, energy management and emergency response. [Tang, Shu, et al] A case study carried out in Hong Kong by Zhai (2019) [Zhai, Yue, et al] concerns the development of modular integrated constructions by using an IoT-enabled BIM platform during the operational phase. The combination of IoT and BIM allows for expanding the possibilities of object management. According to the achieved results, the platform supports autonomous decision making by collecting real-time information, helps to control the construction and procurement process and processes emergency signals. Such an approach addresses the matters related to inconvenient data collection, incomplete information and non-automated decision support. According to a study made by Kang (2021) [Kang, Lin], the use of wireless IoT technologies in combination with geographic information systems (hereinafter referred to as GIS) opens opportunities for the landscape design of street architecture. For example, comprehensive consideration of the physiological parameters of the soil, climate and plant community helps to speed up the process of creating a sketch for a future design due to the information available in one source. It also helps to solve the problem of using monitoring tools to plan and execute irrigation programs.

This approach aims to create an automated smart system and therefore reduce the need for specialized staff training. The IoT is also considered an opportunity for further development of Smart cities. Jiang (2020) reveals that the problem of the inconvenient processing of a large amount of information in traditional urban management can be solved through the combination of IoT and cloud computing. Experimental technology introduced in his research is designed to solve the problem of data transmission. The case fields were Intelligent Environment Monitoring, Intelligent Security and Intelligent Transportation [Jiang, Dingfu]. Improved technology helps to avoid failures in the process of data transmission, which raises the efficiency and opportunities of Smart cities. A smart urban environment monitoring system based on wireless IoT technology (Zhihan, 2020) shows how the comfort and intelligence of modern cities can be improved. During the experiment, a wireless system for collecting information was proposed. The network of sensors was connected with the help of street lamps and taxi cars. These elements were chosen as frequently encountered in modern cities, and the installation of sensors in such places was not a problem for implementation in the already existing urban environment. Real-time traffic information and real-time weather monitoring information have been collected [Lv, Zhihan, Bin Hu, and Haibin Lv]. The creation of the system opens up prospects for the further development of modern Smart cities and their operation. The field of Smart housing is also mentioned in the bibliometric analysis carried out by Choi (2021). The study includes an analysis of existing scientific publications in the Scopus database limited by selected conditions such as the time of publication from 2015 to 2019. From selected sources, the frequency of mentioning IoT and smart housing was investigated. Results indicate that the smart home Internet of Things become a significant emerging area of research since 2016 and relies on state-of-the-art technology [Choi, Wonyoung, et al].

The impact of IoT is mentioned in the field of renewable energy sources by Wu (2022). The paper presents the implementation of IoT into solar photovoltaic panels. The complete integrated design of building systems and photovoltaic units can be achieved due to the IoT benefits. It is said that the improved system helps to increase the level of integration, energy efficiency, reliability, energy consumption level and effective monitoring measures. As the result was presented the solar cell system based on an IoT with such advantages as reduced cost and high efficiency [Wu, XiuFeng, et al].

Using IoT with fuzzy framework technology for smart home and sustainable energy monitoring systems infrastructure was proposed by Alowaidi (2022). The suggested system, which focuses on wind and solar power, was tested using experimental calculated data about insulation, wind speed and energy prices. Thanks to the created device, an increased level of optimization was achieved. the operator could work in real time, and part of the input data was used to predict the possible behaviour of the device, so it is possible to analyse and plan the stable operation of the devices based on it [Alowaidi, Majed]. Another review in the field of smart energy systems, made by Ahmad (2021), shows the possibilities of IoT for energy consumption and infrastructure improvement. Moreover, it claims that the energy business models based on IoT technology are more profitable for businesses. The positive effect can be achieved due to big data handling, the ability to identify critical and potentially critical issues and automatization of the processes. Reducing energy storage demand and costs can be achieved by the comprehensive implementation of IoT [Ahmad, Tanveer, and Dongdong Zhang et.al]. More practical research was carried out by Muralidhara (2020) to control consumed energy resources. The usual reports on the amount of energy are often expressed by general indicators. For better control was created an Internet of Things based energy meter to measure power consumption at the device level. A smart energy meter is a device that does not require special installation, due to this it can be installed both in households and in industrial buildings. The obtained data was compared with the already available information about the studied devices. Thanks to data on consumer behaviour, consumers can consciously reduce energy consumption and therefore minimize energy costs [Muralidhara, Shishir, Niharika Hegde, and P. M. Rekha]. The ability of IoT to cooperate with FM on the BIM platform is mentioned by Cheng (2020). The data from the BIM model and machine learning algorithms was applied along with the FM system for MEP elements (mechanical, electrical and plumbing) maintenance. The research was directed to the development of a condition monitoring and fault alarm module, a condition assessment module, a condition prediction module, and a maintenance planning module. Based on the results, due to the developed system, the state of the MEP components was effectively predicted and the efficiency of facility maintenance management was improved [Cheng, Jack CP, et al]. In the reviews of Gosh [Ghosh, Arka, et al], possible areas of application of IoT are studied in detail. It is stated that, due to the evolving interdisciplinary nature of the building field, it can be applied in different phases of the building life cycle. The main highlighted topics are quality control, construction safety, optimization and simulation, data visualization, prefabricated construction and construction waste management. As construction projects are typically characterized by a high level of complexity and a high number of different activities to be carried out, it could be expected that the potential of IoT deployment during the execution of construction works is relatively high and varied. The following paragraphs present selected examples of usage that demonstrate the possibilities of using IoT during the construction phase. IoT is used in the construction industry to monitor quality. For example, Chen (2020) provides the analysis of the usage of IoT for the real-time monitoring of the construction quality of gravel piles. Traditional manual methods of quality control have limitations which might cause imprecisions. The paper develops a digital control system based on IoT which was verified at the construction site of Chengdu Tianfu International Airport. Results of the study proved the reliability of real-time data transmission and helped to optimize the inspection process. More specifically, the safety of the foundation was increased and construction time was reduced. Another study carried out in the field of construction quality was presented by Yao (2021) [Yao, Shuang, et al]. The main goal of the experiment was aimed at improving the quality and bearing capacity of the underground facilities, more specifically quality control of cement mixing pile construction. The issue of health and safety is one of the most important issues on construction sites. Research by Kanan (2018) suggests using IoT to improve workers' safety. An autonomous system that monitors, localizes, and warns workers has been created. The system consists of sensors located on vehicles and wearable devices for workers. The nodes use energy management and storage circuitry to continuously operate indoors and outdoors. Based on test results, back over accident prevention and the smart alerting system for potential hazard avoidance were successfully created [Kanan, Riad et.al].

2.3 BIM and IoT integration for different domains

A prevalent understanding of housing was averred by Borne (2007) in his book titled "The Geography of Housing", where he identified the functionality of housing as a physical facility, unit of structure which provides shelter to occupants; an economic good or commodity which is traded and exposed to market forces as well as used to promote investment. Bourne further saw housing as consolidation of services such as parks, schools, health institutions, location and proximity of certain types of labour; and summarized it as a tool of government to regulate economic growth. Consequent upon this, the relevance of housing to mankind is buttressed through the call for provision of adequate housing to meeting up the scourging demand for it by citizens of different countries particularly in developing countries and Africa.

2.4 Resource monitoring Sensors like Bluetooth

Low Energy sensors and motion sensors were used to track the movement of labors, materials, equipment in complex construction sites. These tracking systems incorporated BIM models to visualize moving paths, hence resource status and labor behaviors could be monitored.

Communication and collaboration

The study from Ibem and Laryea implied that construction operation could be enhanced using real-time communication and collaboration with BIM and IoT devices. Ref. also supported this opinion by suggesting that the BIM model could be correlated with realtime construction data captured from IoT tags, sensors, and mobile devices to enable in-time communication and collaboration among various parties.

Construction performance and progress monitoring

Construction performance and progress monitoring can profit from IoT devices and BIM in many aspects. Firstly, reality data including actual performance, project status (e.g. laser scanned point-cloud data), construction activity and physical context and other real-time project information could be captured with sensors. Integrated with models and BIM tools, these data could be leveraged to monitor the construction process and update construction schedules. In addition, sensors have been used to detect progress data for quality control. For example, Radio Frequency Identification (RFID) and GPS sensors were used to collect position data of construction components for comparison against BIM models. Current research showed some limitations in construction operation and monitoring. Firstly, some of the reviewed articles proposed framework or workflow with only the prototype tests, single use case for a company or limit testing scenarios. Whether these solutions can be generalized or not remains to be investigated. In addition, some prototype tests were based on heavy and expensive equipment in the laboratory which failed to consider the applicability in the real construction site. Furthermore, issues like the cumbersome design of the process, manual data conversion, the reliability of sensor collected data for calculating mechanisms still remains to be streamlined and addressed. Research studies have been successful on a specific use case, like visualization, crane operation, location tracking, and risk warning, however, these solutions are fragmented and there is lack of a more cohesive framework that integrates various sensor's collected data to manifest smart construction site in the future.

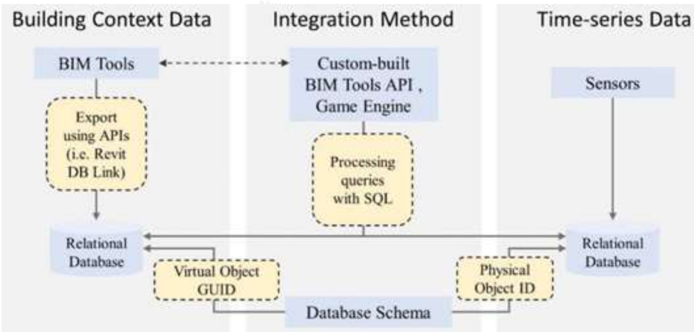

Figure 2.1: BIM tools' APIs + relational database

The second component is the time-series data which records continuous sensor readings. Traditional time-series data is stored in a well-structured relational database and can be effectively queried using Structured Query Language (SQL). The third component is the integration method between contextual information and time-series data. This section explains different integration methods of contextual information (BIM data) and time series (sensor collected) data.

The BIM and WSN system proposed by Marzouk et al. allows the user to read temperature and humidity information from the Revit model in a timely manner. Temperature and humidity data were collected by WSN, stored and updated in Microsoft Access relational database. Revit project data (contextual information) were then exported into Microsoft Access format. Data visualization, importing and exporting was achieved using Revit DB link between Microsoft Access and Revit. Sensor readings were then displayed in Revit as object properties. Zhang and Bai's method can also be categorized into this approach. Revit models were exported to MySQL or MS Access and linked with physical objects using identification. However, this study was only tested with a few structural objects under laboratory condition. The same problem happens to work. If the number of sensors and objects is enormous, a data mapping schema will be necessary to clarify the virtual object and physical objects linking process. More advanced query processing was done by Arslan et al. and Riaz et al.

The real-time H&S monitoring systems also used a relational database and Revit DB link to achieve sensor-BIM integration. They differed from work by creating a GUI as a Revit API using C# language. The GUI once invoked can display latest sensor values. Another example is Woo et al. developed a virtual campus model which integrated BIM, WSN data in a game engine environment for energy benchmarking. WSN was first installed to collect energy data. The Revit DB link plug-in was used to export Revit model into the MySQL database. Sensor data was stored in MS Excel then exported to MS Access relational database before stored in the Revit model. The connection between query and MySQL database was processed by Unity game engine so that real-time energy performance data could be queried. There were other research works implemented with Grasshopper and Dynamo. Habibi developed a prototype smart system using Grasshopper to obtain and monitor real time sensor data. A genetic algorithm was then implemented in Grasshopper to identify the optimized solution. An intelligent user interface allows the user to understand real-time sensor data and take actions based on the optimal solutions. Created a prototype method linking BIM with BMS data. Revit was firstly used to hold model and building design performance data that had been extracted into JSON using Dynamo. Continuous sensor data was stored in a SQL server. A Python script was used to extract sensor data stored in the SQL database and link it to JSON file.

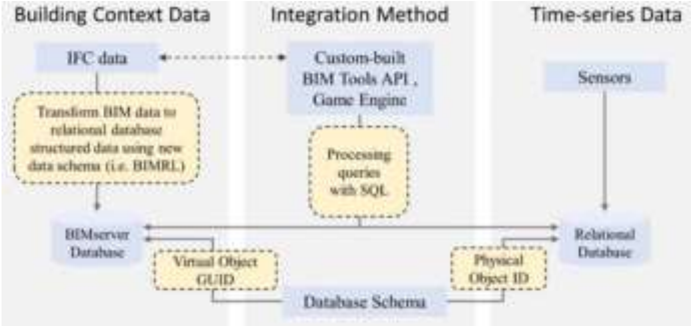

Fig 2.2 Transform BIM data into relational database using new data scheme

Solihin et al. Created a new relational database schema named BIMRL to transform BIM data into a queryable database. BIMRL allowed efficient SQL queries on BIM data without storing entire IFCSTEP data in a database, BIMRL schema was generated using the relational database structure following the star schema definition in the Data Warehouse (DW) domain. BIMRL extended BIM data query capability by integrating spatial set operations into standardized SQL. BIMRL showed potential applications in rule checking, facility management, sensor data integration and real-time optimization of building operations. The prototype system in also converted BIM data into a relational database through manipulation on IFC. Various sources of facilities' data (e.g. sensor readings stored in the relational database) were integrated with BIM. Logical and spatial relationships between entities were manually added to IFC file and mapped to Microsoft Access relational database. GUIDs were used to link entities, related attributes, data sources throughout the whole system. User applications can be instantiated using SQL queries based on the manually coded relationships.

Kang and Choi tried to transform BIM data into a database based on a proposed BIM perspective definition (BPD) metadata structure. The BPD metadata structure was used to bind BIM and facility management, and achieve data extraction based on users' queries. Multi sources data including BIM objects, facility management data and sensor data was extracted, transformed and loaded (ETL) into a

DW database based on BPD metadata structure. Data were linked with BIM objects via OBJECT_GUID and expressed as BIM object properties. Users were able to view requested metadata in XML format based on their purposes. Another example was the IFC-based graph data model for topological queries created. The research proposed a new schema named graph data model extract analysis and represent topological relationships among 3D objects. Although this new data model did not transform the BIM model into a relational database, it enabled topological queries on building elements (e.g. virtual sensor objects).

One example could be found in Mazairac and Beetz's study. They proposed a domain specific query language named BIMQL to select and partially modify IFC-based BIM models. BIMQL allowed selection of objects and attributes based on schema names or arbitrary properties for example Ifc Sensor. However, this method had a limitation in query real-time sensor data. The language was developed to query IFC based BIM model, only static sensor information that stored in IFC-based BIM model can be queried. Since it is almost impossible to transform real-time sensor data into IFC format and store in the BIM model, this solution had a limitation in the integration of real-time sensor data with BIM.

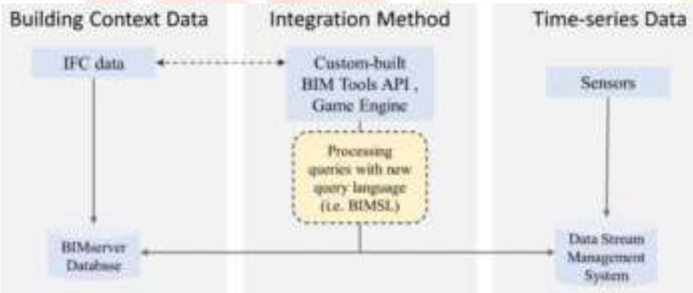

Fig 2.3 Create a new query language

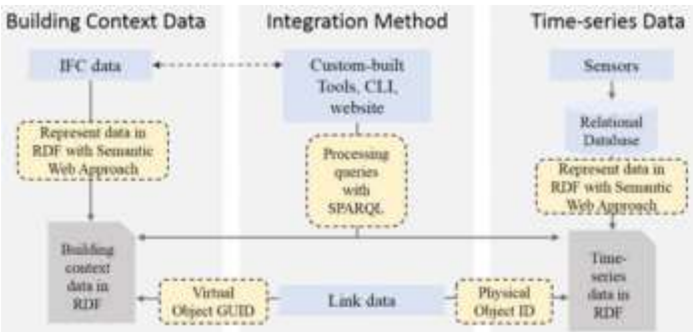

Fig 2.4 Using semantic web technologies

3.0 Methodology

This chapter addresses the methodology adopted for capturing the data, needed to achieve the aim and objectives of the research. The research methodology selected comprised a comprehensive literature review, a postal questionnaire to the construction industry practitioners, a statistical analysis of the survey data and a systematic exploration of identified the local building material for construction through researcher's perspective.

3.1 Materials and Methods

(Antonino Mannino et.al)This study analyses and categorises existing studies on BIM and IoT integration for FM according to the methodology shown in Figure 3.1. To review BIM-IoT integration comprehensively in the Facility Management context, two electronic databases of peerreviewed literature have been taken into consideration: Scopus and Web of Science (WoS). The bibliometric analysis presented here aims to analyse academic publications and trends to evaluate the existing research performance and understand patterns. As the first step, keywords to select articles on BIM-IoT integration for FM functions are defined. Table 1 highlights the keywords used to find publications on BIM and IoT. Table 2 shows the set of keywords for each FM core competence.

Table 3.1: Keywords used for research in the two electronic databases of peer-reviewed literature Scopus and Web of Science (WoS). The asterisk "*" after the keywords tells the search engine to look for all the words beginning with that keywords, i.e., "sensor*" tells the search engine to look for the words "sensor", "sensors", "sensoring", etc . The quotations marks surrounding two or more words tell the search engine to look for the phrase and not the words, i.e., "industry foundation classes" is use to search for the prhase and not for the words industry or foundation or classes.

Table 3.1: Keywords

Tools	Keywords
BIM	BIM or "Building Information Modelling" or "Building Information Modeling" or IFC* or "industry foundation classes"
IoT	IoT or "Internet of things" or sensor* or WSN or "Wireless Sensor* Network*" or "Real Time Data" or "Real-Time Data

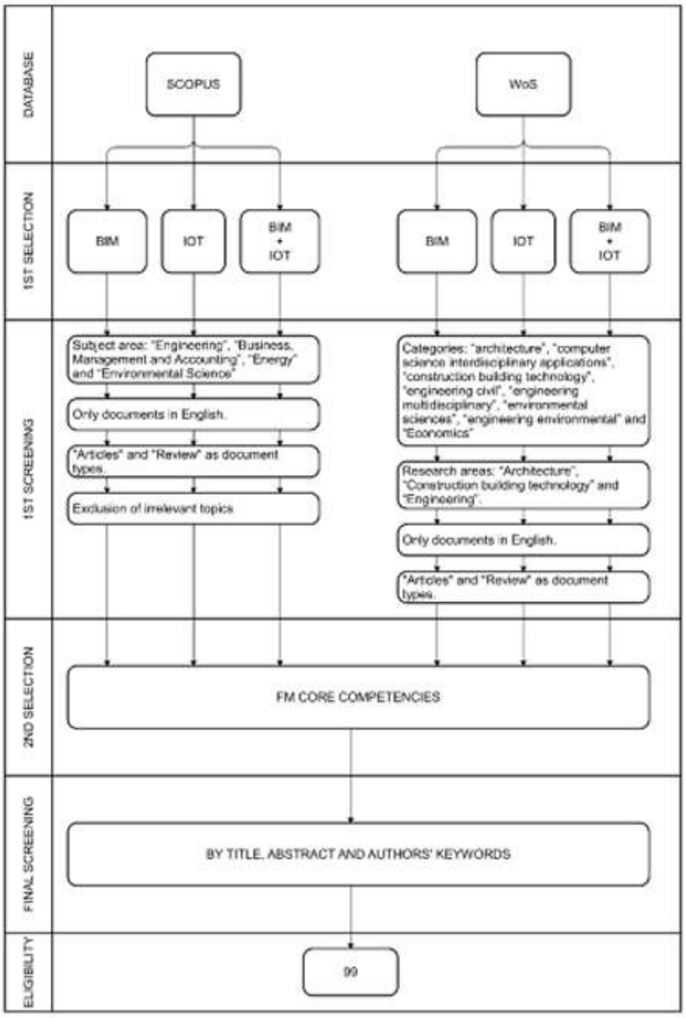

Figure 3.1: Methodology

After the keywords selection, Scopus and WoS databases were queried, using the keywords shown in Table, to find publications dealing with: (a) BIM; (b) IoT; and (c) BIM and IoT at the same time. This first-level query investigated how much these topics have been explored by researchers, even outside the FM field. In a second-level query on the two databases, BIM and IoT keywords (Table) were coupled with FM core competencies (Table 2) to measure how deep BIM and IoT permeate FM core competencies.

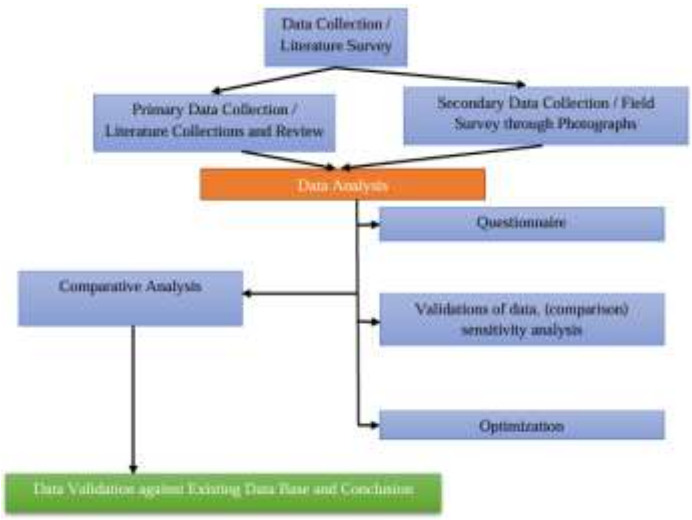

Figure 3.2: Methodology

4.0 Results and Discussion

This chapter addresses the results and its related its discussion through methodology adopted for capturing the data, needed to achieve the aim and objectives of the research. The research methodology selected comprised a comprehensive literature review, a postal questionnaire to the construction industry practitioners, a statistical analysis of the survey data and a systematic exploration of identified the local building construction through researcher's perspective.

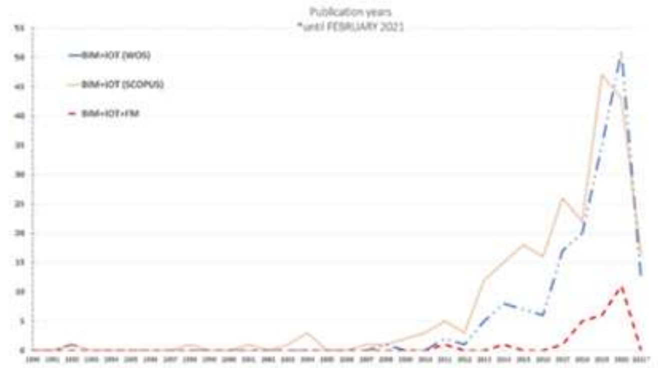

Figure 4.1 Number of publications per year

FM Core Competence: Finance and Business

The Finance and Business core competence concerns economic aspects, and it deals both with significant financial investment and operational expense. The only article concerning this competence proposes a framework in which blockchain technology, smart sensors, smart contract and BIM are integrated. The proposed framework is meant to guide IT developers to design and implement an automated payment system (based on these new technologies) that aims to solve the security of payment problems. This application of multiple advanced technologies simultaneously and its related workflow are new to the current body of knowledge from both technical and managerial perspectives. In the article, smart sensors, at critical points across the entire supply-chain, provide live location and status information automatically onto a BIM model. Furthermore, smart sensor data are also stored on the blockchain network, providing an alternative system that will allow automated payment of fulfilled contractual obligations, resolving late-payment or non-payment-related issues. Although this research's findings have undeniable advantages, this study is based on a specific blockchain platform. Further studies could adopt other blockchain platforms more suitable in upholding the security of payment. Furthermore, the research does not consider human tampering to commit fraud during the process. Even the authors suggested that subsequent studies should also consider fraud or any other human interventions that may influence systems operation. Hence, additional security layers and/or network security techniques should be investigated. Finally, a possible main limitation of this framework hindering its adoption in the construction industry is the need for readily available money. The framework, providing automatic payment upon completion of the work, would jam in the case of lack of funds. If the client were temporarily experiencing a shortage of money in the course of the process, the automated payment would be blocked and the entire process would be interrupted. Smart contracts and blockchain technology will undoubtedly be two essential elements in the future of FM. Future research should focus on these new technologies and challenges presented by them during the facility's whole life cycle. Several blockchain platforms should be investigated to provide the most suitable and secure solutions to the issues addressed.

Table 4.1 Human factor core competence: type of sensors used in studies on BIM–Wireless Sensors Network (WSN) integration for indoor environmental monitoring.

Reference	Scope	Issue	Sensors
Marzouk et al. (2014)	Indoor Environmental monitoring	Air quality	Temperature Particulate Matter
Zhong et al. (2018)	Indoor Environmental monitoring	Air quality	Temperature Humidity Noise Light Gas (CO, CO_2, Radon, Methane)
Ma et al. (2019)	Indoor Environmental monitoring	Air quality	Temperature Humidity Wind speed around person
Lin et al. (2020)	Indoor Environmental monitoring	Air quality	Carbon Monoxide Temperature Humidity
Marzouk et al. (2014)	Indoor Environmental monitoring	Thermal comfort	Temperature Humidity
Natephra et al. (2017)	Indoor Environmental monitoring	Thermal comfort	Temperature Thermographic camera
Zaballos et al. (2020)	Indoor Environmental monitoring	Air quality Thermal comfort	Temperature Humidity Noise Light CO, CO_2, TVOC

The integration between BIM and WSN offers great advantages to the monitoring systems developed in the various research studies. Through this integration, it is possible to better visualise a multitude of data relating to environmental monitoring and associated with multiple elements and spaces. Following this integration and creating the database containing all environmental data (e.g., temperature, humidity, light, noise, etc.), it is possible not only to monitor thermal/air quality problems to ensure comfort for users but also to detect the need for maintenance of building components. However, during these processes, interoperability between different information systems and information sharing between various stakeholders remains challenging. Management of these heterogeneous data should be further investigated. Moreover, battery capacity and operation duration could be a significant limitation of a WSN. Therefore, it is necessary to consider adopting high-capacity batteries or a fixed power source for long-term operation. To conclude, protecting the environment in which people live/work is certainly among the priorities that FM will have to face in the near future. Although the use of new technologies and sensors is widespread and certainly not new, the main challenge for this (but also other) core competencies is data/information interoperability. Finally, a novelty that emerged in this review is the improvement of the comfort level in facilities spaces through users emotion detection. In this direction, more effort should be focused to better f it building spaces to users.

FM Core Competence: Leadership and Strategy

This core competence focuses on aligning the facility portfolio with the organisa tion's missions and available resources. According to IFMA [13], sub-competencies in "Leadership and Strategy" include:

1. Strategic planning and alignment with the organisation requirements;
2. Policies, procedures and compliance;
3. Individual and team management;
4. Relationship and conflict management;
5. Change management;
6. Corporate social responsibility;
7. Political, social, economic and industry factors affecting facility management.

There are few studies on this competence as for the previous one. After refining the query, only two studies remained. Both articles deal with "decision-making" from two different points of view. Niu et al. (2016) discuss several scenarios about using smart construction objects and their augmented capabilities of sensing, processing, computing, networking and reacting to alleviate human beings' incapability in decision making. The Industry Foundation Classes (IFC) format is adopted to represent these objects in a virtual environment. With their innovative properties, smart construction objects can contribute to data collection and information processing and make autonomous decisions, eliminating human errors in the process and saving time.

5.0 Summary / Conclusion

This research focused on the deployment of BIM and IoT within selected phases of the construction management, namely the construction and operational phases. The aim of this research was not to provide a systematic review of the topic, however, we aimed to focus in more detail on specifics of IoT usage during the construction and operational phases of the facility's in construction management perspective. The analysis of data generated by sensorized building components and systems will allow using connected digital models to improve future design and increase the digitally built environment. This document provides an overview of BIM and IoT integration in FM, Existing gaps and future research directions were outlined. Several researchers have begun to explore the potential synergy between these two environments. From the literature review, it emerges that the BIM and IoT integration research is in an early phase. Most research works are still in the conceptual stage, even though some studies are quite thorough and propose solutions tested in real-world applications. However, to take advantage of this transformation, the integration of data into BIM models needs to be managed in the best possible way. BIM and IoT studies are often based on proprietary files and closed ecosystems, where information is not yet shared openly among stakeholders. These are related to the back-propagation of information from the use stage to the design one, to new technologies exploitation and final users' involvement in improving buildings sustainability. This may help further research advancement for studies to improve built Construction management.

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