Health Building Information Modeling (HBIM)-based Facility Management: A Conceptual Framework

Tan Tan[1], Zigeng Fang[2]*, Yuanwei Zheng[3], Yufeng Yang[4]

Abstract:

The outbreak of the COVID-19 epidemic has brought significant challenges to building operation and occupant health. In practice, building operators have begun to use various Internet of Things (IoT) technologies, intelligent sensing devices, and manual registration methods to update occupant information and behaviour in different building areas. Building spaces are classified according to their health, such as the distinction between safe areas and infected areas. Using the health data of occupants and spaces to help buildings operate efficiently and safely is a problem that needs to be solved urgently. This research proposed a conceptual framework for facility management driven by a Health Building Information Model (HBIM). The framework aims to incorporate the emerging data types to enrich the health information of the BIM model and provide decision support for facility operation and maintenance.

Keywords: BIM; Health Building Information Modelling; Facility Management; COVID-19

1. Introduction

The memory of people worldwide is marked by an explosion of a severe viral infection, COVID-19. The virus is highly infectious and could lead to fatal acute respiratory problems. After the swift suffusion of this virus globally only a few weeks' time, COVID-19 was announced by the World Health Organization (WHO) as a pandemic and a global emergency (Sohrabi *et al.*, 2020). The worrying thing in this outbreak is the widespread and persistence of the epidemic, especially for many of the developing countries. As a result, billions of citizens are confined to their dwellings. This raised an urgent need for building professionals to rethink how the building, as the forefront of protection against the pandemic, can help provide a healthy living environment for the residents (Rice, 2020).

Building Information Modelling (BIM) is recognised as a continuously evolving and revolutionary approach for building construction and operation (Altohami, Haron and Law, 2021). Defined by Wong and Zhou (2015) (p157) as "*a model-based process of generating and managing coordinated and consistent building data that facilitates the accomplishment of established sustainability goals.*", BIM has proven to be able to provide a series of high-level evaluations and analysis includes the subject from construction and demolition waste management to carbon emission (Altohami, Haron and Law, 2021). These analyses, presented in the 3D model format, are extracting the interdisciplinary data from various sources (Wang, Cho and Kim, 2015). Facility managers can use BIM as a centralised data platform to work on the "as-is" information, avoiding the issues of fragmented data sources (Altohami, Haron and Law, 2021). This digitisation trend in the built environment is a major driving force for innovation in the Architecture, Engineering, Construction, and Operation sector. However, the lack of data and information (e.g., location

[1] Tan Tan
The Bartlett School of Sustainable Construction, University College London, UK

[2] Zigeng Fang,
Corresponding author, The Bartlett School of Sustainable Construction, University College London, UK, email: zi.fang.15@ucl.ac.uk

[3] Yuanwei Zheng
School of Architecture,Tsinghua University, Beijing, China

[4]Yufeng Yang
The Bartlett School of Architecture, University College London, UK

data from resident's smart devices) has limited the potential of BIM in providing a healthier built environment for the user of the building (Mannino, Dejaco and Re Cecconi, 2021).

To tackle the data and information limitation of BIM, researchers have looked into the data sources coming from technology like the Internet of Things (IoT) (Zhu *et al.*, 2018; Tang *et al.*, 2019). IoT is stated by Asghari, Rahmani and Javadi (2019) (p241) 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". Recently, more and more IoT researchers moved their focus from the connection purely between physical objects to the interconnection between the people and objects (Gubbi *et al.*, 2013), which potentially provide the chance for building user to make better building management decision during this pandemic situation.

Previously, the majority of the BIM and IoT integrated researches have put their focus on the construction operation and monitoring (67.27%) and Facility Management (FM) (21.83%), with only over 5% of studies examine the field of Health and Safety (H & S) management (Mohammed *et al.*, 2020). The existing BIM and IoT integration researches focus mainly on the Health and Safety (H & S) training (Teizer, Cheng and Fang, 2013; Li *et al.*, 2015) and construction onsite monitoring (Kiani, Salman and Riaz, 2014; Riaz *et al.*, 2014; Kanan, Elhassan and Bensalem, 2018). None of these 5% studies investigated whether the BIM provided with IoT data sources can be used to monitor the environmental and human activities associated with the health and safety risks under the threat of COVID-19. This research attempts to explore a healthy BIM and IoT integration model to provide a building environment solution for providing a healthier building environment.

2. Health Building Information Modelling (HBIM)

2.1 The impacts of COVID-19 on BIM-based facility management

There is no doubt that COVID-19 has significantly influenced the health and living style of people worldwide in the past year (Rice, 2020). After "lockdown" or other forms of quarantine become the new routine of many districts for many countries, building professionals now need to reconsider the architectural design and building management requirements of people, as this dramatic changing of living style caused even more human being to spend more than 90% of their time indoors (Samet and Spengler, 2003). The building has played a more significant role in people's lives than ever before. Even though BIM has proved to guarantee efficiencies in a wide spectrum of building-related fields, including material waste, financial control and sustainability performance, little research has been applied BIM to safeguard and evaluate human health (Rice, 2020). Lu et al. (2017) comment that the currently available tools for integrating health index into BIM are limited. Moreover, the widely applied national lockdowns and home-based quarantine also brought new challenges to traditional facility management. For instance, the reliance on online delivery food (Scaraboto, Joubert and Gonzalez-Arcos, 2020), the widely use of potential infectious used-up Personal Protective Equipment (Herron et al., 2020), and the risk of indoor human-to-human infection have all brought challenges for the facility management and the utilising of BIM.

2.2 Healthiness of building space

With an increased amount of time spent indoor, the healthiness of building space has been valued by even more people. An improved indoor living environment can reduce hospital admission, which reduces the pressure over the public health system, especially at this critical moment (Rodgers et al., 2018). The evaluating of the healthiness of a building space relies on the Health Indicator (HI). Health indicator is defined by Farrell and Hart (1998) (p3) as: "something that provides useful information about a physical, social, or economic system, usually in numerical terms." Similarly, the Architecture Health Indices (AHIs) provide the building professionals with a quantitative way of monitoring and evaluating the healthiness of the building. Unfortunately, many of the available AHIs are still included, as an extension, by green building certificates' indicator tools (Rice and Drane, 2020). Even for the certificates that contain the COVID related building healthiness evaluating elements like Indoor Air Quality (IAQ), the assessment criterion is far from perfect. Taking IAQ as an example, the main pollutants can be divided into three categories: suspended particles, volatile organic pollutants, and micro-organisms (Liu et al., 2017). The COVID related pollutant – microbes under the micro-organisms category are only considered by 32% of the certifications (Wei, Ramalho and Mandin, 2015). It is suggested that the emergence of the pandemic has brought new challenges and a higher requirement for testing the completeness and applicability of existing AHIs.

2.3 BIM-centred IoT Deployment

To fully embrace the benefits of BIM as a unified building information management and visualisation platform in tackling COVID-19, the data sources from the various IoT devices (e.g., sensor, personal mobile devices, etc..) need to be considered. IoT is viewed as an architecture that utilises and links different types of intelligent devices like sensors, actuators, smart mobile devices, and computers (Dehury and Sahoo, 2016). Because IoT allows a huge amount of live data to be stored in different repositories, the facilitation of the integration of IoT and BIM becomes the key to the success of many building innovations in the building environment (Altohami, Haron and Law, 2021). Besides the immature BIM-IoT integration (Tang et al., 2019), the potential of BIM-IoT integration in providing a unified framework to enable innovative applications cannot be taken lightly. Due to the pandemic, the IoT linkable technology like Digital Contact Tracing (DCT) has been used to replace the traditional manual-based contact tracing method and proved to be effective in understanding the disease spread patterns and people's routes among neighbouring (Shahroz et al., 2021). The same logic enlighten a new potential for the BIM-IoT integrated application to safeguard the building occupants' health under this pandemic situation.

3. HBIM-based facility management

3.1 Concept of HBIM-FM

The authors define Health Building Information Modeling (HBIM) as a model-based process of generating and managing coordinated and consistent building healthiness data that facilitates the accomplishment of established health goals. HBIM is regarded as a dynamic process tracing the real-time healthiness performance of building spaces. This concept highlighted the importance of healthy building space in facility management. Traditionally, the attention to FM is physical and tangible assets in buildings, such as equipment, IT systems, and logistics. The building performances, such as cleaning, security, environment comfort, and fire safety, are easily perceivable by manual inspection, simple tools and usual methods. However, the healthiness of buildings relatively invisible and not easy to be observed and measured. The outbreak of COVID-19 raises concerns about the performance of building healthiness. In COVID-19, hospitals are divided into the contaminated area, semi-contaminated area, and clean area. Spaces such as airports and offices are extremely vulnerable to infectious diseases. The authors take account these concepts into HBIM. Building spaces can be infected by virus attaching to objects, people or indoor air. Regular disinfection, cleaning and ventilation can reduce the risk of viruses in indoor spaces. Based on the aim, principles, and background, a tentative definition is given as:

Health Building Information Modeling-based Facility Management (HBIM-FM) is a methodology to encompass multiple data sources to ensure healthiness, safety and comfort of the built environment by integrating people, place, process and technology.

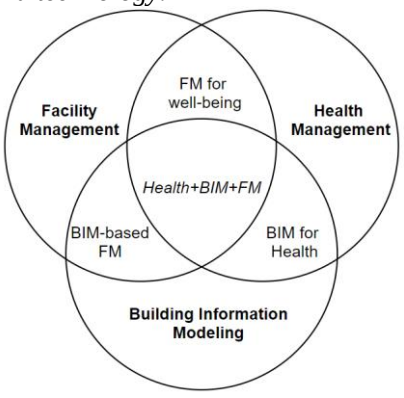

Figure 1: Health+BIM+FM

3.2 Characteristics of HBIM-FM

3.2.1 HBIM-centred IoT perception

The outbreak of COVID-19 has enriched health-related data for buildings. For example, contact tracing has become a common intervention method to control highly infectious disease spread (Sharma et al., 2020). In some countries, people are required to scan a QR code to register or fill in information when entering buildings or different areas of facilities. Cameras are widely adopted. Face recognition and ID card information entry have been set up in many hospitals. Digital contact tracing apps can synchronise with BIM to form a digital twin of health information. In some densely populated buildings, such as hospitals, the daily

flow of people reaches tens of thousands, which brings significant challenges to the health and maintenance of the building and generates a large amount of real-time data.

Thus, one of the most significant characteristics of HBIM-FM is the HBIM-centred IoT perception. IoT devices can be integrated with BIM to achieve a new paradigm of building operation efficiency improvement (Tang et al., 2019). The implementation of information technology to manage COVID-19 has accelerated the installation of various sensors and IoT devices, contributing to the basis of HBIM-centred IoT. These smart devices are capable of perception in the ambient environment and collect user behaviour patterns (Xu et al., 2019). Perception interprets sensors to provide the system with information about the environment (Russell and Norvig, 2002). However, the integration between HBIM and IoT is still in its infant stage, and further research should explore how to utilise this integration for the practical situation in FM.

3.2.2 Architecture health indices

The building can significantly affect people's health. Compared with many articles focusing on improving the health performance of buildings in the design stage, the author of this article attempts to establish the factors that affect human health in the building operation stage and use them as the basis of HBIM-FM. HBIM also includes and considers the performance of building comfort because comfort affects the quality of the building space and affects human health.

Additionally, it is suggested that spatial configuration can also influence the health performance of the building (Pachilova and Sailer, 2020). A recent study, for example, reported that higher visibility and accessibility led to a higher frequency of healthcare worker's hand-hygiene behaviours in hospitals (Cai et al., 2021). Abundant space syntax studies have repeatedly evidenced that the spatial configuration largely determines pedestrian movement distribution, thus co-presence pattern and potential interactions among people (Hillier et al., 1993, Dietz et al., 2020). This relationship is arguably essential for understanding and reducing virus transmission such as COVID-19. For instance, an empirical study of Hong Kong, China, concluded that more confirmed COVID-19 cases were identified at places with high centrality (i.e., accessibility) (Yao et al., 2021).

Therefore, the configurational (or geometric) properties, along with physical (or non-geometric) indicators, can be used to evaluate the health status of a space comprehensively. A good reference is the 'Healthy Street Index' [1]that rates London streets considering both geometric (e.g., connectivity) and non-geometric features (e.g., the presence of trees, sidewalk width). Undoubtedly, indicators for a "healthy street" are different for a "healthy building". However, there is a lack of such an index for a building space at this moment. The authors hence aim to contribute in this regard.

Table 1: HBIM related data sources

Environment health data	Human health data
Air quality	Face recognition
Window area	Fingerprint recognition
Ventilation speed	Disease test result
Population density	Phone verification/registration
Indoor Temperature	Registration form
Humidity	Contact tracing app
Noise	Camera
Luminous intensity	Body temperature
Disinfection frequency	Travel record
Cleaning frequency	Medical report

3.2.3 Multi-criteria decision assistance

BIM-enabled Multi-Criteria Decision Making (MCDM) has been widely used in the operation and matainance stages of the building life cycle (Tan et al., 2021). There are many decision makings in HBIM-FM, and MCDM techniques can be used to assist facility managers. MCDM can usually be used to make decisions about abstract concepts, such as sustainability and safety. These manmade concepts can usually be defined, decomposed, measured, and tested with a series of indicators. Building space health is also an

[1] https://www.ucl.ac.uk/news/2021/jan/map-shows-londoners-how-healthy-their-neighbourhood

abstract concept quantified and defined by many indicators. MCDM provides a technical method for processing AHIs data. As shown in Figure 2, there are five strategies to promote multi-criteria decision assistance (Tan et al., 2021). The authors tried to adapt these strategies to the HBIM context for FM, including: (1) to define the goal of decision-making by a set of rationale AHIs; (2) to fully exert the function of HBIM; (3) to specifically design the synergy approaches between HBIM and MCDM for FM; (4) to adopt corresponding MCDM techniques and data collection methods to adapt to the characteristics of the building operation stage; (5) to optimise the information richness of HBIM to satisfy the requirements of applied MCDM techniques.

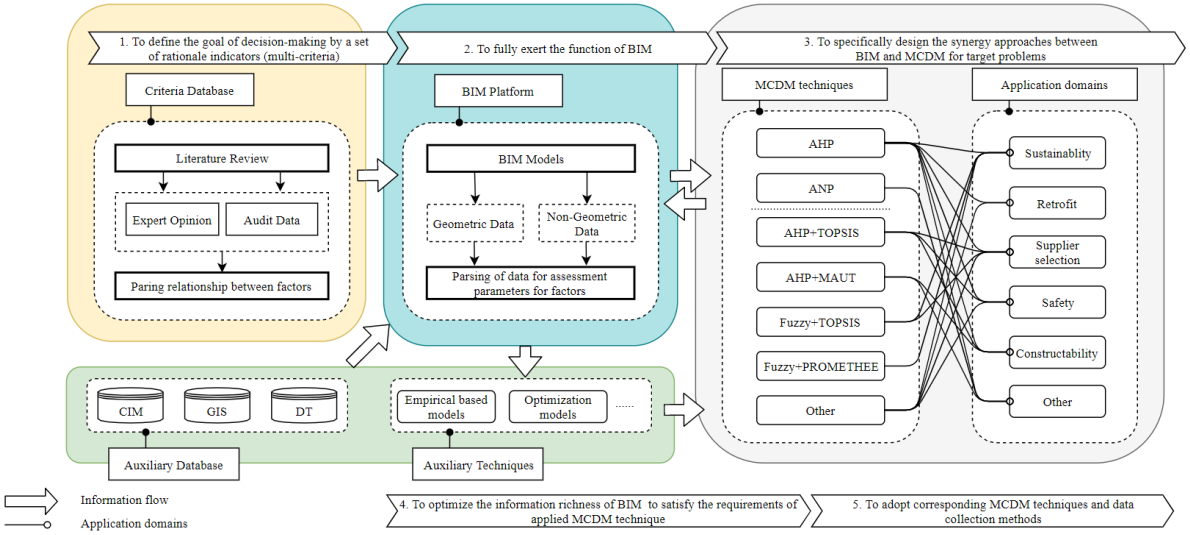

Figure 2 BIM-enabled MCDM process (Tan et al., 2021)

3.3 Conceptual framework

The framework of HBIM-FM is shown in Figure 3. Various sensors will be used to collect data about environment health performance, such as air quality, ventilation speed, and cleaning frequency. In the initial stage, human detection and machine detection will be combined to identify and recognise these data. Data from online health systems will be used to support and enrich human health data. In practice, these data have been used widely in current epidemic control, including epidemic test results, travel records, and medical reports. The update of this data between online health systems and BIM relies hugely on the building entry process control. The strict control of building users' information registration would contribute to the information enrichment of HBIM. Also, buildings sensors would help the human health data collection. For example, human body temperature test devices have been used in many buildings. If there is a fever patient, the building operations staff will respond quickly to avoid the expansion of possible risks and the expansion of unhealthy areas. Finally, all these data will be integrated into the BIM model.

This BIM model will then provide data for AHIs. In AHIs analysis, multiple approaches will be applied to evaluate the building performance on health. For instance, space syntax computation will be conducted to analyse the building layout. Places with high potentials for pedestrian movement (i.e., high accessibility) will be highlighted. These places could be highly risky for virus infection due to the dense co-presence of people brought by the building layout per se. Meanwhile, space syntax analysis can also quantify the compactness of a layout. A compact room with poor ventilation condition is not conducive to keep social distancing and thus control the virus spreading. Furthermore, space syntax can be used as a simulation to analyse the proposed or redesigned building layout and predict their risk level. Based on this result, an adjustment of the building layout can be made to separate infected and uninfected people by providing different routes. All in all, the result of AHIs, as the multi-criteria for decision assistance, thus enabling facility managers to make more scientific decisions and adjustments. Subsequently, these factors will be weighted by the facility managers and BIM data. MCDM will be used to process these AHIs to support the FM process. The ultimate goal is to improve human health data, which is the core of HBIM-FM.

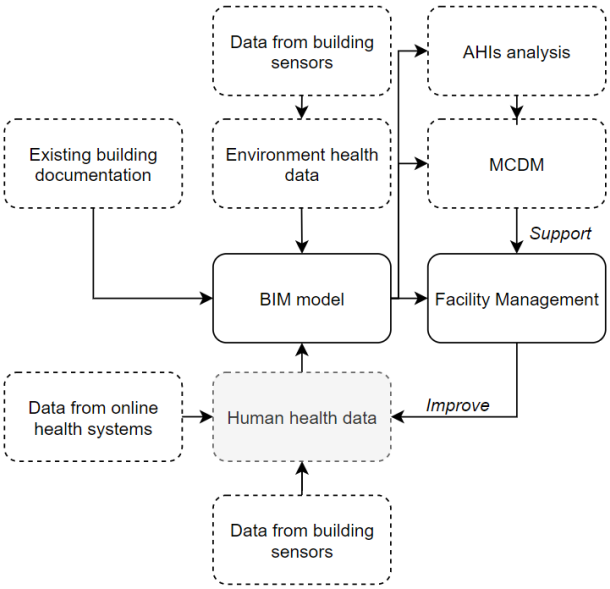

Figure 3 Framework of HBIM-FM

4. Discussion and Conclusion

4.1 The adaption of new normalcy

When the number of COVID-19 infections in the United States and the United Kingdom decreases due to the vaccination, many developing countries like India are suffered from a second COVID-19 surge and bring uncertainty to the worldwide pandemic prevention and control (Thiagarajan, 2021). More and more people aware that they need to learn how to live with COVID-19 like an ordinary Influenza because it will last much longer than people originally expected. Building environment will also learn to adapt to this new normalcy.

4.2 Potentials of HBIM-FM

The integration of HBIM-FM and IoTs will open many opportunities for coping with the new challenges brought by COVID-19. Firstly, the data collected through high accuracy wireless technologies like Bluetooth and Geolocation Wifi and the building IoT equipment like Motion sensor, if integrated into the 3D-BIM, can provide the historical path of the anonymous COVID-19 carrier inside the building in 3D. If this information is further integrated with the indoor air quality data (e.g., ventilation rate), the zones with high contamination rates can be highlighted and visualised by building managers. Different levels of emergency responses and treatment tools can then be selected and decided hierarchically. For instance, for the high-risk zone, the ongoing event for the affected zone will be canceled, and the people who have entered the zone and stay closed to the potential carrier will be informed and advised for further testing. Accordingly, the high-risk area will be given a higher standard of disinfection accordingly.

4.3 Challenges of HBIM-FM

The collecting and analysis of human health data also raise some challenges for the HBIM designer and related stakeholders. The privacy and ethical issues related to using an individual's sensitive information are potentially the major obstacles to the development of HBIM. To assess the healthiness of the building, especially in this new COVID-19 normalcy, the collection of personal health information is unavoidable. Although there are already some technologies like Efficient Privacy-preserving contact-tracing for Infection Detection (EPIC) (Altuwaiyan, Hadian and Liang, 2018) and Encounter-based Architecture for Contact Tracing (ENACT) (Prasad and Kotz, 2017) that claimed to provide privacy-preserving contact tracing, there are still many questions, like where the data should be stored and when should be collected data be destroyed, wait to be answered. Besides that, the mobile tracing app's adaptability brought another major barrier to the realisation of HBIM-FM. For instance, UK's NHS COVID-19 App only has a 28.5% adoption rate, while India's Arogya Setu has only a 12.05% adoption rate (Shahroz et al., 2021). If most people don't use the app, it is hard for an HBIM-FM system powered by the data from these apps to be effective. Furthermore, there are challenges related to the selecting and setting-up of counter-COVID AHIs. There is still a long way to go before the realisation of HBIM.

4.3 Conclusion

This paper has raised the concept of HBIM-FM for improving the healthiness of the building environment from multi-dimensional and emphasised the impact of COVID-19 over the HBIM-FM. The data from traditional BIM-centred IoT and the personal mobile IoT are suggested to play an important role in this new normalcy caused by COVID-19. With the help of MCDM and collected AHIs data, HBIM-FM can help facility managers provide a healthier living and working environment for future building users.

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