BIM Related Technology Enabled Facility Management for Buildings: Challenges and Potential Research Directions

Hoai Nam Le[1], Trung Kien Nham Sy[2], Quan Nguyen[1]*, Ngoc Binh Ta[3], Phuong Nam Tran[1]

[1] *Faculty of Construction Economics and Management,*
  Hanoi University of Civil Engineering, 55 Giai Phong Street, Hai Ba Trung, Ha Noi, VIETNAM

[2] *Institute of Investment and Construction Management, Hanoi University of Civil Engineering*
  2nd Floor, Building A2, Hanoi University of Civil Engineering,

  55 Giai Phong Street, Hai Ba Trung, Ha Noi, VIETNAM

[3] *Institute of Construction Economics, Ministry of Construction*
  No. 20 The Giao, Hai Ba Trung, Hanoi, VIETNAM

*Corresponding Author: quannt@huce.edu.vn
DOI: https://doi.org/10.30880/ijscet.2024.15.04.010

Abstract

The operation and maintenance phases of the buildings, featured by great time and cost consumption, always contain a variety of complex issues, risks and uncertainties, all of which significantly impact on buildings' performance. Many cutting-edge digital technology applications are proposed to effectively manage operation and maintenance tasks, and BIM and BIM-related technologies (such as iBMS, sensors and IoT) stand out as the best options because of their advantages for the information management process. In this research, a literature review on the application of BIM and BIM-related technologies for facilities management was conducted in order to measure the challenges of such technologies' application and potential research directions toward the topic. The results pointed out a number of issues in terms of BIM enabled facilities management, then discussed on challenges and potential research directions on the BIM-FM system for building sector, including: (1) improving and managing data input quality, (2) identifying frameworks and processes for transferring data between BIM and existing operation management systems with the aid of advanced technologies, and (3) developing completely automated BIM enabled facilities management for the goals of automation and sustainable development.

1. Introduction

The global population is projected to increase from almost 7.8 billion in 2020 to over 8.5 billion by 2030 [1], resulting in a surge in the demand for buildings such as housing, production facilities, and commercial spaces. In

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

131

2020, the global construction output amounted to US$10.7 trillion. It is projected to increase by 42%, equivalent to US$4.5 trillion, between 2020 and 2030, with an expected value of US$15.2 trillion [1]. Furthermore, by 2050, due to the dramatic upsurge in the global population, it is estimated that the construction of 13,000 buildings per day will be necessary [2]. The construction process from planning to design usually spans 2-3 years, while the operational and maintenance phase can last for up to a decade [3]. The cost of the operational phase typically makes up about 50% of a project's total lifecycle costs, which can increase up to 80% for infrastructure projects, accounting for a total cost four times greater than all remaining stages combined [4]. Effective operation management requires critical tasks such as data collection, storage, analysis, and evaluation. Nevertheless, recent research has revealed that information related to operation management is presently collected, processed, and distributed in a fragmented fashion, stored in various formats, and lacks centralization, uniformity, and forecasting capabilities. Consequently, these shortcomings can result in errors, delays in resolving urgent situations, and adversely impact the operational decision-making process, leading to reduced operational efficiency of the project.

Currently, Building Information Modeling (BIM) represents a prominent trend within the construction industry and has been widely implemented in the Architectural, Engineering, Construction and Operation (AECO) industry, particularly during the design and construction phases [5]. BIM can be considered a virtual process that encapsulates and extracts information in a unified, digital, and collaborative model, making it well-suited for optimizing facility management activities. BIM has the potential to assist facility management in several ways:

• It can integrate updated data and live information into a single, synchronized, and shared model.

• It can sort and classify information to ensure that it is exchanged smoothly, thereby solving problems related to overlapping information.

• It can simulate and forecast possible incidents, allowing for better planning and preparation.

• It can support facility management decision-making, thereby enabling improvements in building energy efficiency and promoting sustainable construction practices.

Given these advantages, BIM can serve as a fundamental tool in developing an advanced operation management solution that can be implemented across the entire project life cycle.

Therefore, the objective of this paper is including:

• To introduce key terms and summarize the literature on integrating BIM-FM systems.

• To identify the main topics through theoretical taxonomy and systematization techniques, providing stakeholders with a comprehensive understanding of how BIM can enhance facility management activities for buildings.

• To summarize the challenges and potential research directions for BIM-FM integration.

To achieve this goal, the paper is structured into seven sections. Sections 1: Introduces the topic and details structures. Section 2 details Facilities (Facility) management and BIM. Section 3 details the scientific methodology in this research paper and develop a descriptive analysis. Section 4 delivers a discussion on Integration of BIM into Facilities (Facility) Management (referred to as BIM-FM system) and Information management for BIM-FM system. Section 5 delivers discussion on challenges and potential research directions for the BIM-FM system. Section 6 delivers a conclusion. The results of this review contribute to the field by providing an overview of the current state of BIM-FM integration, identifying gaps in the literature, and offering a foundation for future research to address the challenges and opportunities within this domain.

2. Facilities (Facility) Management and BIM

2.1 Operation Management and Facilities (Facility) Management

According to the Oxford dictionary, "management" refers to organizing and controlling activities in accordance with specific requirements while "operation" means specific tasks that each component of a system must complete in order to cooperate with the other components [6]. Therefore, if the aforementioned system is a building, the term "building's operation management" may refer to activities that are organized and controlled to ensure the proper function of each building's component and the collaboration between these components for the effective performance of this building. Three (03) aspects associated to the operation and management phase of building are taken into consideration including "asset management", "property management", and "facilities (facility) management". Asset management refers to a systematic and strategic procedure for the efficient operation, management and upgrading of tangible assets throughout their life cycle [7]. In other words, asset management aims to maintain and optimize assets' performance of buildings, more specifically, it focuses on (1) evaluating the

status quo of assets; (2) predicting future asset failures; (3) selecting and developing strategies and plans on assets maintenance and repair; (4) enhancing assets' performance after maintenance and repair; and (5) developing plans on assets prioritization and capital allocation for asset operation [8]. Property management is the day-to-day oversight of real estate, including apartment, commercial, and industrial buildings, by a contractor acting as a third party (agencies providing operation management services, for example). Thus, these agencies are in charge of carrying out daily upkeep, repairs, and protection of assets (or real estates) [9], and the term "property management" is also involved in buildings' operation and maintenance activities for the smooth and efficient functioning of these facilities. Facilities management or facility management is a specialized area containing the participation of various disciplines in order to assure the function of the buildings based on the integration of people, space, procedure and technology [10]. The phrase "facilities management" and the previously described concept "operation management" have comparable meanings. The two concepts place a strong emphasis on cross-disciplines collaboration [11] for efficient assets' operation. This word "assets" can be used to represent not only specific kinds of assets in a building but also entire buildings, complexes, or even entire cities [12]. The basic goal of "asset management" is to optimize earnings for the entities that hold the assets, or, to put it another way, the advantages of the asset's owners, "property management" gets appropriately used when studies are put into practice with the primary subjects as businesses or agencies that offer operation management services, while "facilities (facility) management" refers to a field of comprehensive managing all operation and management activities, with an emphasis on buildings . In the literature review process related to buildings' operation and maintenance, the term "facilities management" or "facility management" is frequently used to describe the process of managing the operations of buildings, therefore, this study primarily considers "facilities (facility) management" as "operation management".

2.2 Building Information Modelling (BIM)

Building Information Modeling (BIM) is the digital representation of all building components' physical characteristics and functions [13-15]. BIM owns potential benefits for investors and operation management agencies by offering a sophisticated tool for obtaining, utilizing, and managing numerous types of data output from the digital models of assets, or the buildings [3]. The operation and maintenance phase are the most time-consuming and have the most impact on the life cycle of a structure. It involves a number of simultaneous tasks that are conducted to maintain the buildings' effective operation [8]. Nevertheless, the role of BIM for operation and maintenance phase is restricted to a platform that provides a database and information for operational process, therefore, BIM must be incorporated into other cutting-edge technologies (hereinafter referred as "BIM-related technologies"), such as sensors, internet of things (IoT), mobile technology and intelligent Building Management System (iBMS), to deliver the best support for buildings' operation and maintenance phase [7].

3. Methodology

This study adopted the method of collecting, synthesizing, and analyzing research documents pertinent to the field of construction management and operation and the application of BIM. Theoretical taxonomy and systematization techniques are utilized to categorize the documents into distinct problem groups and organize a theoretical framework relevant to this research [16, 17].

This research paper was developed through a four-stage process shown in Fig.1, commencing with source and keyword identification, followed by bibliometric analysis, analyzing contents of selected research, and concluding with a discussion on the BIM-FM system, information management system for BIM-FM system, challenges, and potential research directions for BIM-FM system.
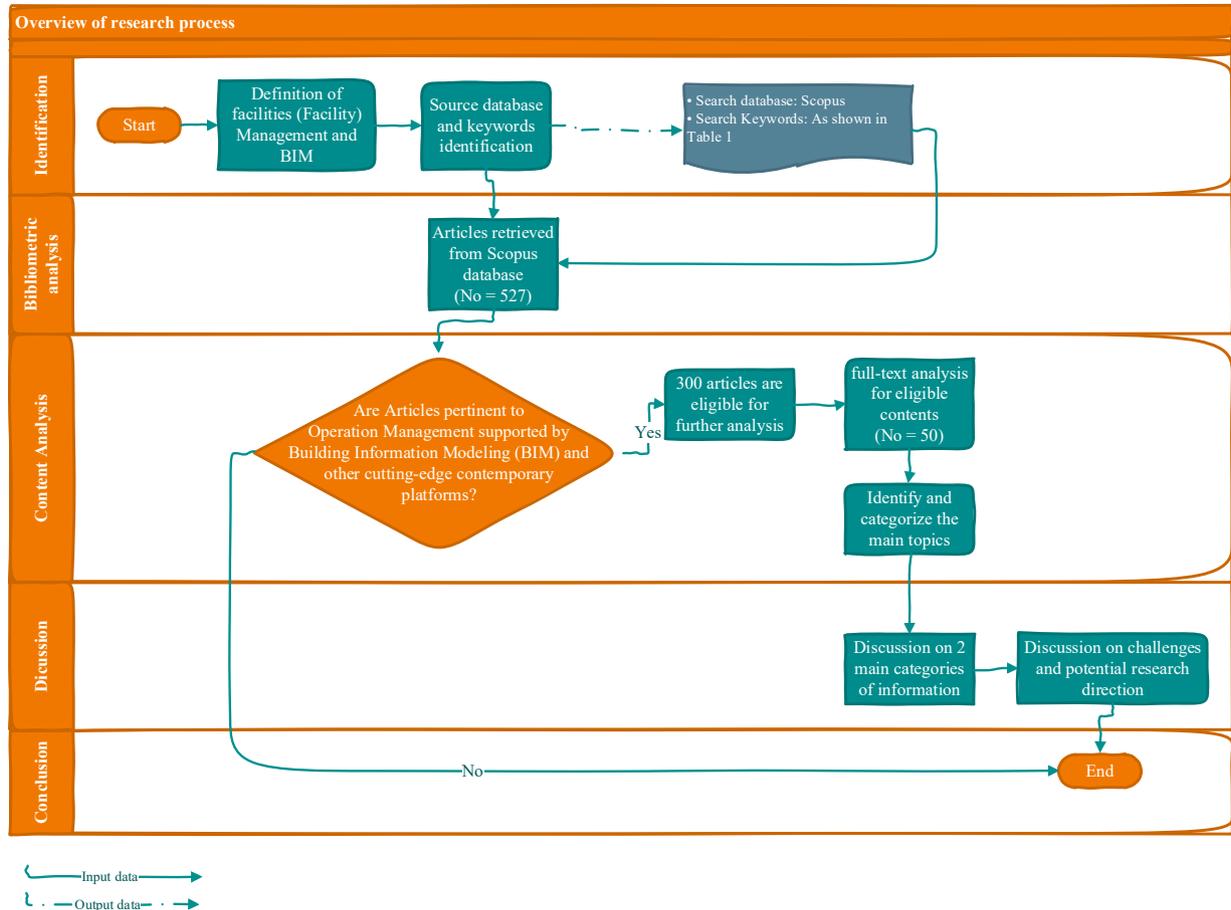
Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

133

Fig. 1 *Overview of research process*

3.1 Stage 1: Source and keywords identification

The database employed to search for publications was Scopus, which is a standard that ensures the quality of research papers and conference papers from around the world.

Regarding keywords, two categories were established to gather the most pertinent information related to this study, as illustrated in **Table 1**.

Even though the majority of this study focuses on "facilities management," 02 other terms, including "asset management" and "property management," are also taken into consideration because of their shades of meaning representing various operational management aspects and their overlap with the facilities management area. In other words, a variety of research on facilities management might even mention property management and, especially, asset management, hence, in addition to the phrase "facilit* management," the keywords "asset management" and "property management" are also utilized as crucial keywords to ensure the representativeness of this research.

Table 1 *Search terms categories used for search*

Search terms Categories	Search purposes
Search terms: ("**BIM**" OR "**Sensor**" OR "**IoT**" OR "**Mobile technology**" OR "**BAS**" OR "**iBMS**") AND ("**Facili***** management**" OR "**asset management**" OR "**Property management**")	The search criteria were established to retrieve and gather scholarly documents for general analysis, in-depth analysis, and synthesis of research studies on operation management utilizing cutting-edge technologies (such as BIM, BAS, external devices, etc.)
Search terms: ("**BIM**" OR "**Sensor**" OR "**IoT**" OR "**Mobile technology**" OR "**BAS**" OR "**iBMS**") AND (**keywords pertaining to operation and maintenance management activities, as depicted in Table 2**)	The search criteria were established to retrieve and gather scholarly documents for general analysis, in-depth analysis, and synthesis of research studies on operation and maintenance activities applying cutting-edge technologies (such as BIM, BAS, external devices, etc.)

Table 2 *Keywords pertaining to operation and maintenance management activities [18-27]*

No	Operation and maintenance management activities
1	Maintenance and repair
2	Energy management
3	Emergency management
4	Change/Relocation management
5	Space management
6	Security
7	Hazardous waste management
8	ICT management
9	Recycling
10	Inventory management
11	Furniture installation
12	Disaster recovery
13	Cleaning and housekeeping
14	Landscape maintenance
15	Interior finishes selections and maintenance

3.2 Stage 2: Bibliometric Analysis

Drawing on the definitions of Facility Management and BIM outlined in Section 2, we conducted a search in the Scopus database using the following terms: "BIM" AND ("Facilit* management" OR "Asset management" OR "Property management"). The search was restricted to the field of engineering and articles published in English between 2009 and 2022. From these databases, a total of 527 articles were retrieved, including international journal papers (347 articles), conference papers (52 articles), and review papers (reviews - 82 articles), and the few remaining documents are Editorials, books, and chapters related to the research problem. Fig.2 illustrates the publication types of articles searched with the following phrases "**BIM**" AND ("**Faciliti* management**" OR "**Asset Management**" OR "**Property Management**").

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145
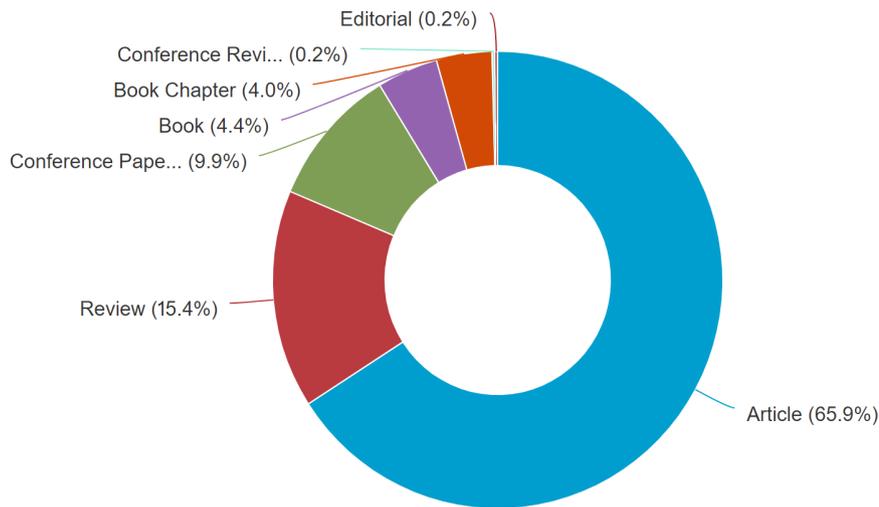
135

Fig. 2 *The type of distribution of selected articles*

The bibliometric analysis reveals the annual publication of the articles within the period from 2009 to 2022, indicating a notable surge in publications related to facilities management and building information modeling (BIM) beginning in 2017 (Fig.3). Between 2017 and 2018, fewer than 50 publications were recorded annually. In contrast, during the preceding period, the number of articles did not exceed 25. These findings demonstrate that the research on developing and innovating facility management processes with the support of cutting-edge solutions and technologies is a relatively nascent field globally, having only emerged in the past 4-5 years (since 2018).
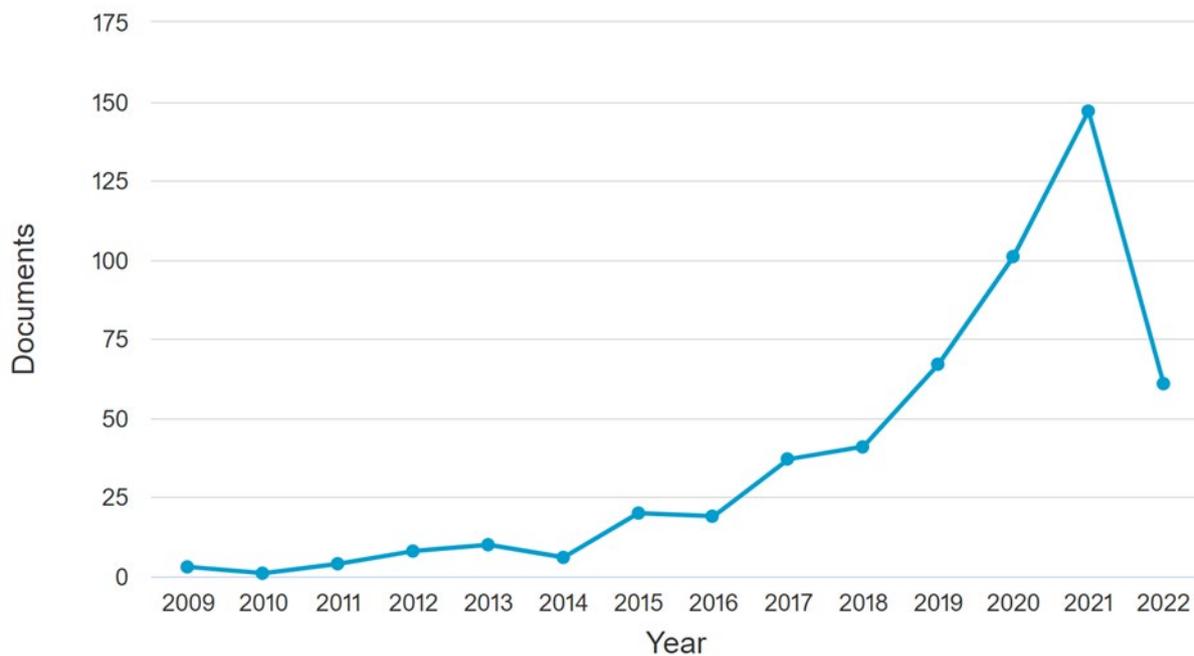

Fig. 3 *The distribution of selected articles by year*

In terms of origin of publications, the bibliometric analysis shows that most articles regarding both facilities management and Building Information Modeling (BIM) originate from the United Kingdom (UK) and Australia, with the United States (US) following closely behind. In Asia, only China, Malaysia, and Hong Kong have demonstrated significant interest in this field.

Documents by country or territory

Compare the document counts for up to 15 countries/territories.
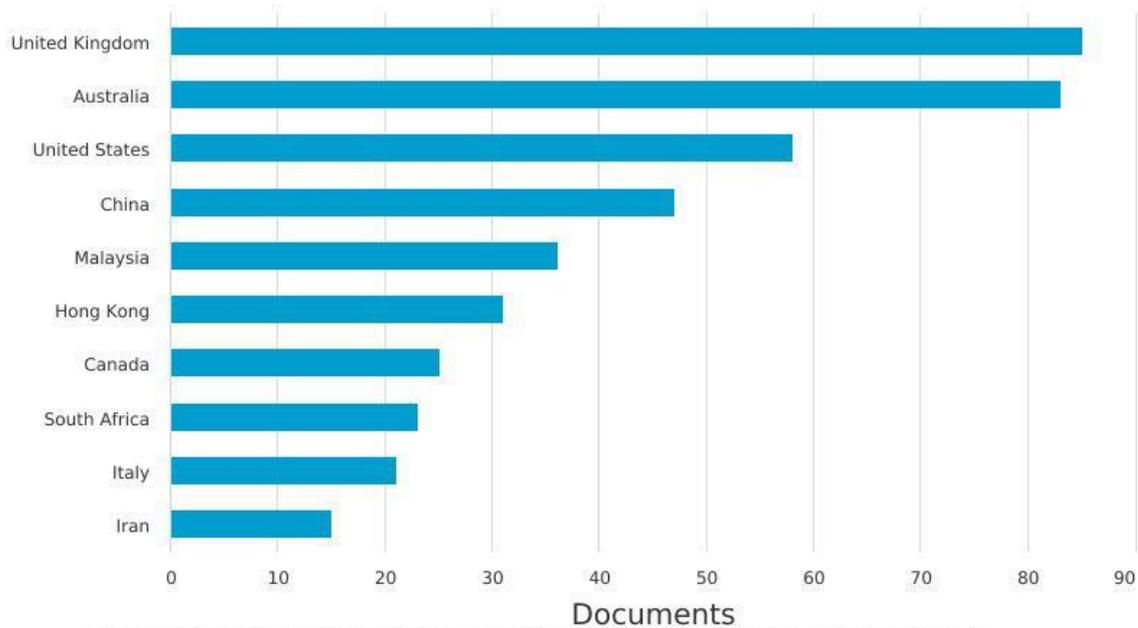
Scopus

Fig. 4 *Distribution of publication by territory*

The bibliometric analysis also demonstrates that the BIM, Data, Information, Operation, Process, Technology, Approach, are the most frequently used keywords as shown in Fig 5. The keyword's frequency assisted us in clustering the selected publications in sis 3 clusters after combining the common interest of keyword as follow: (1) Information management (includes: data, building information modelling, environment, approach, system); (2) integration of BIM (includes: operation, process, phase, lifecycle, integration, standard, requirement); (3) Future research (includes: challenges, research, study, construction, stakeholder, understanding, organization, benefit, design methodology approach).

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

137

Fig. 5 *Keywords co-occurrence mapping*

Fig. 6 *Keywords cluster analysis visualization*

3.3 Stage 3: Analyzing Contents of Selected Research

This stage comprised scrutinizing the abstracts of 527 articles to pinpoint publications that are directly pertinent to this study, which contain or address the following contents and relevant keywords:

• Contents related to construction industry and construction building, with keywords including "Construction industry" or "Civil Engineering", "Construction building", "Office building", "Green Building", "Housing", "Intelligent Building".

• Contents related to operation management, with keywords including "Facilities management", "Facility Management", "Asset Management", and "FM".

• Contents related to buildings' operation and maintenance stages, with keywords including "Maintenance", "Operation and maintenance", "Maintenance management", "Building maintenance".

• Contents related to Building Information Modelling (BIM), with keywords including "BIM", "Building Information Modelling", "Building Information Modelling - BIM", "Building information Modeling (BIM)", and "3D Modelling".

• Contents related to cutting-edge platforms supporting building operation management, with keywords including "Digital Twins", "Internet of Things" or "IoT", "Augmented reality", and other advanced technologies.

The filter yielded 387 articles that fulfill the aforementioned criteria, of which the majority pertain to "Facilit* management," while only a few mention "Asset management" (27 documents), and none discuss "property management." Therefore, it can be inferred that the research direction of construction operation management worldwide, supported by Building Information Modeling (BIM) and other cutting-edge contemporary platforms, primarily focus on two main aspects, namely "Facilit* management" and "Asset management", with "Facilit* management" constituting a larger proportion compared to the latter.

The authors of this study aim to focus analysis on the most compelling research problem, as mentioned earlier, which is the development of an advanced FM system that leverages BIM and other relevant cutting-edge technologies. To achieve this objective, the authors adopt a method of analyzing studies with a narrow scope of research on Facilities Management, with over 300 studies considered, then further select studies that pertinent to the following topics:

• Contents related to the development of BIM enabled facilities management or facility management systems supported by BIM and BIM – related technologies.

• Contents related to cutting-edge platforms supporting facilities management functions (such as DT, iBMS and IoT) Contents related to cutting-edge platforms supporting building operation management, with keywords including "Digital Twins", "Internet of Things" or "IoT", "Augmented reality", and other advanced technologies.

Following the selection of related studies based on the above-mentioned topics, we have identified and chosen over 50 relevant articles for in-depth analysis. These topics were then categorized into two key categories containing four main topics of information. The relevant papers pertaining to each topic were scrutinized, summarized, and compared to extracting significant findings, conclusions, research gaps, and current limitations, thus enabling a thorough and insightful discussion.

3.4 Stage 4: Discussion

This section presents a discourse on the two primary categories of information related to BIM - FM system, encompassing "BIM-enabled facilities management knowledge sharing" and "The development of BIM-FM's framework or process", as well as Information management for BIM-FM system, involving "Information transfer" and "Information Interoperability". Building on this discussion, we subsequently examine the challenges and potential research directions for the BIM-FM system.

4. Discussion

4.1 Integration of BIM into Facilities (Facility) Management (Referred to as BIM-FM System)

Most of the studies conducted from 2013 to 2017 highlights knowledge sharing and introduction of BIM adoption as a platform of data development, management and transfer in order to assist facility management, then proposes processes and frameworks for BIM applications. Due to the novelty of BIM applying for FM, the BIM-FM system's obstacles, challenges, and benefits are examined and stressed. In addition, future research directions are specified for a comprehensive facility management process supported by BIM.

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

139

4.1.1 BIM Enabled Facilities Management Knowledge Sharing

In 2015, the BIM functions for FM are highlighted in a book's chapter of Ghosh [28], then, the recommended direction for BIM-FM research includes: (1) BIM implementation plan for facilities management, (2) Legal data integration into BIM-FM system, (3) BIM-FM Contracts' requirements establishment and the process of performing operation tasks in terms of legal aspects, (4) Remote control of facilities management process, (5) Simultaneous information sharing in both BIM models and FM system, or development of live BIM-FM system, (6) The information compatibility between BIM tools and FM system, and (7) Development of an intelligent building system equipped with self-repair and self-maintenance mechanism. In addition to BIM's benefits for enhancing FM efficiency, It is considered as a solution for sustainable construction orientation, however, BIM - enabled sustainable facilities management must overcome 04 challenges as follows: (1) Identification of necessary information required for operation decisions, (2) Development of new BIM- models or adjustment of existing BIM-models of buildings, (3) Management of information sharing for operation activities, of systems monitoring operational process and BIM models, and (4) risks management only based on insufficient building data [29].

4.1.2 Development of BIM-FM's Framework or Process

In the period of 2013 to 2017, the focus of research is on the topic of BIM integration into Facility Management. In 2013, BIM is proposed to incorporate with smartphones to support for facility management activities, more specifically, smartphones are used to provide an engineer with the implementation of facility management tasks, such as establishing maintenance schedules, checking and monitoring the state of the assets, even when he (she) is not on site, and BIM integrated into these devices aims to provide engineers with detailed and visible information on a buildings' components, and assist them in controlling the status quo of asset and in making better operational decisions [30]. Nevertheless, to develop a successful BIM – FM system, the quality of input data must be prioritized first. Regarding this issue, an open BIM standard is applied to create an intelligent facility system. The difficulty in gathering geometric information for facilities management is emphasized, therefore, a BIM enabled process of objects' properties recognition is developed to directly and continuously transfer BIM models data into the facility management system [31]. This process prevents operational management agencies from re-developing assets data and guarantees the quality of input data.

For large projects containing complicated equipment and MEP systems, multi-scale BIM models, or BIM models that may adjust their volume based on the needs of each participant, are developed and applied [32]. Moreover, data from BIM models is also utilized to evaluate the condition of building assets, facilitating the ability for operation management agencies to monitor the state of building assets and facilities by using BIM models directly instead of manually importing input data [33]. Advanced-technologies are studied to incorporate with BIM to support facility management, including digital technologies [34] and sensors [35], in addition, information models on building's assets, equipment and facilities that can be used and transferred from the construction phase to the operation phase are suggested [36, 37]. Moreover, early in the construction project, an information system on building assets operation and management must be developed, and the information system must reflect the inheritance, which means it may be used efficiently throughout all project phases, including the project's preparation phase, the design and construction phase, and the operation and maintenance phase.

4.2 Information Management for BIM-FM System

As previously indicated, research from 2013 to 2017 focused on knowledge exchange and the introduction of BIM applications for FM, whereas from 2018, issues related to building's information and information management are addressed, with a particular emphasis on the development of a database for information transfer and interoperability between BIM models and facilities management systems.

4.2.1 Information Transfer

In 2018, COBie, a data format for archiving information or a standard for data sharing which facilitates the ability to transfer data between different application programs, is proposed to support the integration of facility management data into BIM, especially the transfer of building information from the construction phase to the operation phase [38]. Additionally, the system for exchanging building operation information is based on tools for collecting, archiving and sharing necessary data, that can be classified into 04 groups as: (1) data on assets characteristics, (2) data on physical facilities, (3) data on operation and maintenance activities, and (4) data on operation mechanism and alternatives for making decisions. Besides, 04 aspects that contribute to facilities management include (1) input data for the operation framework, (2) lists of building assets and equipment in the

140

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

operational process, (3) practices on the implementation of facilities management, and (4) Information Technology tools used [39]. To control the quality of data input for asset management, a reliable data collection process is proposed to be used for existing infrastructure projects, involving the following steps: (1) preparing technologies factors such as software and tools, (2) gathering data from available documents and the construction site, (3) verifying data collected and (4) updating data into information databases for asset management [40].

Furthermore, BIM integrated with a live database (or referred to as a cloud platform for archiving data) is a method for developing information management systems, and then provides a significant instrument to control the risks and variables associated with facilities management during the operation and maintenance phase [41]. As a response to the emergence of sophisticated facilities management solutions like BAS (Building Automation Systems), a data connection structure, or an integrated technique used to connect data obtained from BAS sensors installed in the building to BIM-FM models, is being researched. More specifically, a convention for naming data and techniques on time series data analysis is established and integrated into the database, and then incorporated with 3D networks to enable the reflection of time-series data to BIM-FM models and to facilitate the data visualization [42].

4.2.2 Information Interoperability

Regarding to the information interoperability between BIM and facilities management, a suggestion is made to link the building's components in BIM models and the information of facilities management into a single operational database, which is known as Semantic Web - a group of languages used in layers to maximize data value and protect data security [43, 44]. In addition, regarding to the improvement of the input data collection process, Internet of Things (IoT) is suggested to integrated with BIM through the use of real time applications for building status monitoring, nevertheless, in order to ensure the efficiency the data collecting process, numerous IoT devices are installed into the buildings, so a management system for these devices must be developed [45]. On the other hand, further issues arise from the BIM, IoT, and FM systems' data sharing and interoperability because each system uses a different data format and data presentation, and to overcome this challenge, a framework based on an 04 phases ontology database [46], an application of Digital Twins (DT) and artificial intelligence (AI) [47, 48] are presented. Digital Twin (DT) is proposed to support the facilities management automation process. DT represents its advantages in real-time assets information management to quickly identify dangers and accidents for automated buildings' equipment operation [49, 50]. In addition to advanced software solutions, hardware devices are employed to support the BIM-FM system. Data obtained from sensors can be combined with data from BIM models in order to establish a comprehensive database of buildings [51], Unmanned Aircraft System is used to monitor the state of the buildings' facade [52], and Ultrasonic sensor networks are applied to optimize the maintenance services for smart buildings [53].

5. Challenges and Potential Research Directions for BIM-FM System

5.1 Challenges for BIM-FM System

As a result of the descriptive analyses indicated above, BIM enabled facilities management is mostly focused on studies from the 2016s when BIM demonstrated its outstanding benefits in the AEC industry. BIM offers an information platform to connect all disciplines involved in project' segmentation of construction projects, more specifically, all the building information related to every construction projects' phases, including physical and non-physical data, is collected, imported, visualized and continuously updated under a consistent protocol to create the information platform, or the information database of the building, which serves as the basis for the creation of numerous BIM uses aimed at improving the efficiency of construction projects. To be aware of the importance of information in BIM, to develop an effective BIM-FM system, the first challenge in creating a successful BIM-FM system is the management of data input quality, especially in case of existing buildings not applying BIM in their design and construction phases. For these kinds of buildings, particularly those constructed many years ago, deliverables from earlier phases are only available as paper records or 2D drawings, and difficulties arise when building information is digitalized due to data inaccuracy and insufficiency. Furthermore, when developing digital models, an unclear identification of operation and maintenance requirements leads to incorrect data input. The efficiency of data digitization, a time- and money-consuming process that requires the application of numerous modern technologies, depends in part on the quality of the data input.

The review on the BIM-FM system demonstrates the use of a variety of cutting-edges technologies and solutions for managing building operations such as intelligent Building Management System (iBMS) and Building

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

141

Automation System (BAS), which contain many application levels based on the operation of various software and tools. These aforementioned systems only operate effectively in case of using a comprehensive database, which can be accomplished by deploying BIM, or the integration between BIM and operation management systems need to be studied and implemented, unfortunately, this integration has difficulties with data sharing, exchange, and interoperability. Various tools used for BIM and for these systems are used, therefore, data extracted from BIM and operation systems may differ from each other on format, size and other properties, and then, can not be transferred directly between BIM models and operation management systems. Additionally, each operation management system is owned by a different organization and then has its own set of protocols for data collection, import, transfer, access, and export as well as a unique method for carrying out tasks related to operation and maintenance. As a result, it is difficult to find a consistent process, or framework, or platform to connect data from BIM models to operation management systems to create effective operation management tools that run on an extensive information database.

Automation and sustainable development have been becoming an outstanding movement in the construction industry, and the operation and maintenance phase of buildings - with its feature of high cost-consuming, long-lasting duration and significant influences on environment - are supposed as a fertile ground for in-depth studies on the buildings' performance based on automatization mechanisms to satisfy requirements of sustainable development. The development of advanced technologies such as BIM, Digital Twin, Internet of Thing, iBMS and BAS provides researchers with exceptional materials for performing studies on improvement of operation management efficiency throughout the buildings' life cycle, nevertheless, the complex features of these technologies create challenges for researchers to use and incorporate them into the buildings' operation and maintenance phase. In addition to issues on data management indicated above, risks associated with the operation of BIM-FM systems over the projects' life cycle could create not only barriers but also opportunities for studies focusing on the development of sophisticated operation management systems that facilitate the trend toward automation and sustainable development.

5.2 Potential Research Directions

The first requirement in developing a successful BIM-FM system is the high quality of the data input integrated into models; therefore, data quality management may become a prospective research area in terms of BIM enabled facilities management. Nowadays, the birth of various advanced technologies related to information management, such as Digital Twin and 3D scanning, facilitates the enhancement of the process on data input's collection and quality control, despite researches that were carried out using Digital Twin, RFID tag, sensors and 3D scanning for data management and operation management, research on using these cutting-edge technologies and solutions to control data input quality and perform data processing for the data digitization of various types of buildings, that have different operation and maintenance features and needs, is still in its infancy. Potential directions in the aforementioned research aspect may be more specifically as follows:

• Developing consistent standards or requirements on information needed for each kind of building's operation and maintenance phase while taking into account the operational conditions of the buildings, and the legal environment and status quo on operation and maintenance management in each country. Particularly in BIM lagging behind countries that are creating BIM specifications and standards for widespread use in their construction industries, or are focusing on BIM application for design and construction stages, studies on early identification of data input standards integrated to use for operation and maintenance process facilitate the development of successful digital models even from the earliest stages of construction projects onward, and the creation of an information system that can reflect the inheritance as indicated above.

• Digitalizing all the buildings' information and data by the use of advanced solutions and technologies such as BIM, DT and 3D scanning under the consideration on operation management requirements and relevant legal documents for each kind of buildings, and then developing a protocol or a framework for collecting, selecting, processing and integrating information and data input digitized into available operation and maintenance systems, especially for existing structures that had been built many years ago, and have not yet undertaken the data-digitization process (old apartment buildings or heritage buildings, for example). In other words, this research orientation addresses the procedure of all buildings assets digitalization to support for the operation and maintenance functions, then facilitates the process of developing a comprehensive database in preparation for the construction of smart cities in the future.

Thanks to the expansion of website and blockchain technology, there is still space for research into data exchange, sharing and interoperability between BIM models that are developed in the design and construction phases, and existing building operation management systems. The development of information technologies allows researchers to study on a consistent process or framework or a standard data format to share information, and a protocol to link data from available BIM models into various operation management systems (such as iBMS, BAS and soft and hard FM) in an attempt to efficiently utilize BIM models as an information management platform to support functions of facilities management. Specifically, the following could be potential directions in the research aspect:

• In the first circumstance, BIM models developed in the design and construction phases, need to be modified to apply to the operation and maintenance phase, or to combine with operation management systems that are anticipated to be in use. As a result, the research design emphasis is on the transfers to the identification of information appropriate to the requirements of operation management to incorporate into BIM models generated in the design and construction phase, on the basis of the operational management system chosen, the operational and management data standards and specifications, and the facility management requirements.

• In the second circumstance, BIM models must be re-developed to provide an information database for buildings that are in operation phase and being applied to existing operation management systems. In this case, because the operation management requirements are identified clearly and operation management systems are even in use, the research now focuses on data interchange, sharing, interoperability, and access between BIM models and various operation management tools. Information technologies, such as websites and blockchain, may be the key for this issue with the benefits of sharing, exchanging, safeguarding, and accessing data between various information databases.

Besides, the further researches may concentrate on the development of an automation facilities management or alive facilities management to support for operation needs such as automated energy management, and automated analytics and management of risks arising throughout operation and maintenance phase with the support of various cutting-edge solutions like BIM, DT, IoT, block chain as well as hardware devices (sensors), nevertheless, this research orientation must be facilitated by contemporary and comprehensive digital platforms for buildings, making it appropriate to apply in nations with a high level of BIM and an extensive use and implementation of information technology in their respective sectors.

6. Conclusion

This research emphasizes the various BIM benefits for the operation and maintenance phase of buildings, especially for the activities and functions of Facilities management. Furthermore, the process of completing a literature analysis on BIM-enabled facilities management area highlighted several contemporary topics that researchers are working on. More specifically, 02 significant aspects given extra extension are: (1) development of a consistent process or framework for the BIM-FM system's smooth operation and (2) enhancement of an advanced and effective information management system with the consideration on data input quality, data transfer, and interoperability between different operation management platforms. Based on findings from the literature review process, several future research directions are discussed for the development of entirely automated facilities management and the objectives of sustainable development in the construction sector.

Acknowledgement

The authors would like to thank the Hanoi University of Civil Engineering and Ministry of Construction.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Author Contribution

*The authors firmly confirm contribution to the paper as follows: **study conception and design:** Author Hoai Nam Le, Author Quan Nguyen, Author Ngoc Binh Ta; **data collection:** Author Hoai Nam Le, Author Trung Kien Nham Sy; **analysis and interpretation of results:** Author Hoai Nam Le, Author Trung Kien Nham Sy, Author Phuong Nam Tran; **draft manuscript preparation:** Author Hoai Nam Le, Author Trung Kien Nham Sy, Author Phuong Nam Tran. All authors reviewed the results and approved the final version of the manuscript.*

Penerbit
UTHM

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

143

References

[1] J. L. a. T. W. Graham Robinson. (2021). *A global forecast for the construction industry to 2030* https://www.oxfordeconomics.com/resource/future-of-construction/

[2] V. Bertollini. (2018, March 7). *Here's What Building the Future Looks Like for a 10-Billion-Person Planet* https://redshift.autodesk.com/infographics/building-the-future

[3] P. Teicholz. (2013). *BIM for facility managers*. John Wiley & Sons.

[4] Ajith Kumar Parlikad, James Heaton, Jennifer Schooling (2019) Design and development of BIM models to support operations and maintenance, *Computers in Industry*, 111, 172-186, https://doi.org/10.1016/j.compind.2019.08.001.

[5] Rebekka Volk, Julian Stengel, and Frank Schultmann (2014) Building Information Modeling (BIM) for existing buildings — Literature review and future needs, *Automation in Construction,* 38, 109-127, https://doi.org/10.1016/j.autcon.2013.10.023.

[6] Oxford English Dictionary. Retrieved March 7, 2023, from https://www.oxfordlearnersdictionaries.com/definition/english/management?q=management

[7] Hoang Van Giang and Le Hoai Nam (2020) The combination of BIM and BMS - the optimal solution for high-rise building management technology in Vietnam (in Vietnamese), *Journal of Construction Economics* , *03*, 45-53.

[8] Burcin Becerik-Gerber, Farrokh Jazizadeh, Nan Li, and Gulben Calis (2012) Application Areas and Data Requirements for BIM-Enabled Facilities Management, *Journal of Construction Engineering and Management*, 138(3), 431-442, https://10.1061/(ASCE)CO.1943-7862.0000433

[9] Ozturk Gozde Basak (2021) Digital Twin Research in the AECO-FM Industry, *Journal of Building Engineering*, 40, 102730, https://doi.org/10.1016/j.jobe.2021.102730.

[10] Marco Marocco and Ilaria Garofolo (2021) Integrating disruptive technologies with facilities management: A literature review and future research directions, *Automation in Construction*, 131, 103917, https://doi.org/10.1016/j.autcon.2021.103917.

[11] S. Chung, S. Kwon, D. Moon, and T. Ko. (2018). *Smart Facility Management Systems Utilizing Open BIM and Augmented/Virtual Reality* [35th International Symposium on Automation and Robotics in Construction (ISARC 2018)]. 35th ISARC, Berlin, Germany. https://www.iaarc.org/publications/2018_proceedings_of_the_35th_isarc/smart_facility_management_systems_utilizing_open_bim_and_augmentedvirtual_reality.html.

[12] Clement Mignard and Christophe Nicolle (2014) Merging BIM and GIS using ontologies application to urban facility management in ACTIVe3D, *Computers in Industry*, 65(9), 1276-1290, https://doi.org/10.1016/j.compind.2014.07.008.

[13] C. Eastman, P. Teicholz, R. Sacks, and K. Liston. (2011). *B.I.M. Handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, second ed*. John Wiley & Sons.

[14] *ISO 29481-1:2016, Building information models – Information delivery manual – Part 1: Methodology and format* 2016.

[15] Rebekka Volk, Julian Stengel, and Frank Schultmann (2014) Building Information Modeling (BIM) for existing buildings — Literature review and future needs, *Automation in Construction*, 38, 109-127, https://doi.org/10.1016/j.autcon.2013.10.023.

[16] Muhammad Usman, Ricardo Britto, Jürgen Börstler, and Emilia Mendes (2017) Taxonomies in software engineering: A Systematic mapping study and a revised taxonomy development method, *Information and Software Technology*, 85, 43-59, https://doi.org/10.1016/j.infsof.2017.01.006.

[17] Odiel Estrada Molina (2014) Theoretical systematization of research competence, *Revista Electrónica Educare*, 18(2), 177-194.

[18] Marco Marocco and Ilaria Garofolo (2021) Integrating disruptive technologies with facilities management: A literature review and future research directions, *Automation in Construction*, 131, 103917, https://doi.org/10.1016/j.autcon.2021.103917.

[19] K. Roper and R. Payant. (2014). *The facility management handbook*. Amacom.

[20] B. T. Lewis. (1999). *Facility manager's operation and maintenance handbook*. McGraw Hill Professional.

[21] B. Atkin and A. Brooks (2021) Total facility management.

[22] S. J. F. Chotipanich (2004) Positioning facility management.

[23] E. P. Rondeau, R. K. Brown, and P. D. Lapides. (2012). *Facility management*. John Wiley & Sons.

[24] K. Roper and L. Borello. (2013). *International facility management*. John Wiley & Sons.

[25] M. May and G. Williams. (2017). *The Facility Manager's Guide to Information Technology*. International Facility Management Association.

[26] Vida Maliene, Keith Alexander, and Natalija Lepkova (2008) Facilities management development in Europe, *International Journal of Environment Pollution*, 35(2-4), 171-184, https://10.1504/IJEP.2008.021354

[27] D. Sapp. (2017, March 7). *Facilities Operations & Maintenance - An Overview* https://www.wbdg.org/facilities-operations-maintenance

[28] A. Ghosh, A. D. Chasey, and M. Mergenschroer (2015). Building Information Modeling: Applications and Practices, *Building information modeling for facilities management: Current practices and future prospects* (pp. 223-253). American Society of Civil Engineers (ASCE). https://doi.org/10.1061/9780784413982.ch09

[29] J. J. McArthur (2015). *A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability* [Procedia Engineering] https://www.scopus.com/inward/record.uri?eid=2s2.084948396437&doi=10.1016%2fj.proeng.2015.08.450&partnerID=40&md5=466b3ac66d7d0c2a408d5a096b655b99

[30] H. Kim, C. Kim, H. Lim, and H. Kim (2013). *BIM-based mobile system for facility management* [ISARC 2013 - 30th International Symposium on Automation and Robotics in Construction and Mining, Held in Conjunction with the 23rd World Mining Congress] https://www.scopus.com/inward/record.uri?eid=2s2.084893632849&partnerID=40&md5=72c4544efb7dba7c8830b7242ea005d9

[31] K. Orr, Z. Shen, P. K. Juneja, N. Snodgrass, and H. Kim (2014). *Intelligent facilities: Applicability and flexibility of open BIM standards for operations and maintenance* [Construction Research Congress 2014: Construction in a Global Network - Proceedings of the 2014 Construction Research Congress] https://www.scopus.com/inward/record.uri?eid=2s2.084904600212&doi=10.1061%2f9780784413517.199&partnerID=40&md5=e8998639297507eaa47d18c4590f7f75

[32] Zhen-Zhong Hu, Pei-Long Tian, Sun-Wei Li, and Jian-Ping Zhang (2018) BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase, *Advances in Engineering Software*, 115, 1-16, https://doi.org/10.1016/j.advengsoft.2017.08.007.

[33] K. Kim and J. Yu (2016). *Improvement of Facility Condition Assessment Processes Using BIM Data* [Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan - Proceedings of the 2016 Construction Research Congress, CRC 2016] https://www.scopus.com/inward/record.uri?eid=2s2.084976351799&doi=10.1061%2f9780784479827.242&partnerID=40&md5=87c68a84f9bc696be97ba5b587afd03b

[34] Krystyna Araszkiewicz (2017) Digital Technologies in Facility Management - The state of Practice and Research Challenges, *Procedia Engineering*, 196, 1034-1042, https://doi.org/10.1016/j.proeng.2017.08.059.

[35] K. Suprabhas and H. N. Dib (2017). *Integration of BIM and utility sensor data for facilities management* [Congress on Computing in Civil Engineering, Proceedings] https://www.scopus.com/inward/record.uri?eid=2s2.085021739627&doi=10.1061%2f9780784480823.004&partnerID=40&md5=b8e7a73ffde308407cdca98116079c29

[36] Walid Thabet and Jason D Lucas (2017) A 6-step systematic process for model-based facility data delivery, *Journal of Information Technology in Construction*, 22, 104-131.

[37] Walid Thabet and Jason Lucas (2017) Asset Data Handover for a Large Educational Institution: Case-Study Approach, *Journal of Construction Engineering and Management*, 143(11), 05017017, https://doi.org/10.1061/(ASCE)CO.1943-7862.0001389.

[38] L. Florez Perez and K. Afsari (2018, July 20th - 25th). *Integrating facility management information into building information modelling using COBie: Current status and future directions* [ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things] https://www.scopus.com/inward/record.uri?eid=2s2.085085408379&doi=10.22260%2fisarc2018%2f0116&partnerID=40&md5=5a4ce5ce6065ab70f1b51521379f132f

[39] M. Sadeghi, M. Mehany, and K. Strong (2018) *Integrating building information models and building operation information exchange systems in a decision support framework for facilities management* [Construction Research Congress 2018: Infrastructure and Facility Management - Selected Papers from the Construction Research Congress 2018] https://www.scopus.com/inward/record.uri?eid=2s2.085049202148&doi=10.1061%2f9780784481295.077&partnerID=40&md5=68d70ed05c3686b25f98457c51fb049a

Int. J. of Sustainable Construction Engineering and Tech. Vol. 15 No. 4 (2024) p. 130-145

145

[40] Hamid Abdirad and Carrie Sturts Dossick (2020) Rebaselining Asset Data for Existing Facilities and Infrastructure, *Journal of Computing in Civil Engineering*, 34(1), 05019004, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000868.

[41] L. Pinti, S. Bonelli, A. Brizzolari, C. Mirarchi, M. C. Dejaco, and A. Kiviniemi (2018) *Integrated information management for the fm: Building information modelling and database integration for the italian public administration* [eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 12th European Conference on Product and Process Modelling, ECPPM 2018] https://www.scopus.com/inward/record.uri?eid=2s2.085079326502&doi=10.1201%2f9780429506215-3&partnerID=40&md5=3104694f04a79237dd8633d113780760

[42] Caroline Quinn, Ali Zargar Shabestari, Tony Misic, Sara Gilani, Marin Litoiu, and JJ McArthur (2020) Building automation system - BIM integration using a linked data structure, *Automation in Construction*, 118, 103257, https://doi.org/10.1016/j.autcon.2020.103257.

[43] Karam Kim, Hyunjoo Kim, Wooyoung Kim, Changduk Kim, Jaeyo Kim, and Jungho Yu (2018) Integration of ifc objects and facility management work information using Semantic Web, *Automation in Construction*, 87, 173-187, https://doi.org/10.1016/j.autcon.2017.12.019.

[44] Liu, L., Hagedorn, P., König, M. (2022). Lecture Notes in Civil Engineering. In Pellegrino, C., Faleschini, F., Zanini, M.A., Matos, J.C., Casas, J.R., Strauss, A (Eds.), *BIM-Based Organization of Inspection Data Using Semantic Web Technology for Infrastructure Asset Management* (pp. 1117-1126). Springer, Cham. https://doi.org/10.1007/978-3-030-91877-4_127

[45] E. Kim (2018). *Field survey system for facility management using BIM model: IoT management for facility management* [CAADRIA 2018 - 23rd International Conference on Computer-Aided Architectural Design Research in Asia: Learning, Prototyping and Adapting] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85056088263&partnerID=40&md5=7c34a0dc34d12e41fed959ae91704cd8

[46] W. Chen, M. Das, K. Chen, and J. C. Cheng (2020, *Ontology-Based Data Integration and Sharing for Facility Maintenance Management* [Construction Research Congress 2020: Computer Applications - Selected Papers from the Construction Research Congress 2020] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096788977&partnerID=40&md5=a42ab94e4e233644bc83bc409a3d4aa3

[47] Y. Song and Y. Li (2022, *Digital Twin Aided Healthcare Facility Management: A Case Study of Shanghai Tongji Hospital* [Construction Research Congress 2022: Computer Applications, Automation, and Data Analytics - Selected Papers from Construction Research Congress 2022] https://www.scopus.com/inward/record.uri?eid=2-s2.0-85128978969&doi=10.1061%2f9780784483961.120&partnerID=40&md5=130c43d247d9b24cf1dcc328b55bf7c6

[48] Fan Zhang, Albert PC Chan, Amos Darko, Zhengyi Chen, and Dezhi Li (2022) Integrated applications of building information modeling and artificial intelligence techniques in the AEC/FM industry, *Automation in Construction*, 139, 104289, https://doi.org/10.1016/j.autcon.2022.104289.

[49] X. Xie, Q. Lu, A. K. Parlikad, and J. M. Schooling (2020, *Digital twin enabled asset anomaly detection for building facility management* [IFAC-PapersOnLine] https://www.scopus.com/inward/record.uri?eid=2-s2.085105544642&doi=10.1016%2fj.ifacol.2020.11.061&partnerID=40&md5=b18e05f427c8b66526283835a7f24bf8

[50] Feng Jiang, Ling Ma, Tim Broyd, and Ke Chen (2021) Digital twin and its implementations in the civil engineering sector, *Automation in Construction*, 130, 103838, https://doi.org/10.1016/j.autcon.2021.103838.

[51] Kay Rogage, Adrian Clear, Zaid Alwan, Tom Lawrence, and Graham Kelly (2020) Assessing building performance in residential buildings using BIM and sensor data, *International Journal of Building Pathology and Adaptation*, 38(1), 176-191, https://10.1108/IJBPA-01-2019-0012.

[52] Ramiro Daniel Ballesteros Ruiz, Alberto Casado Lordsleem Jr, Joaquin Humberto Aquino Rocha, and Javier Irizarry (2021) Unmanned aerial vehicles (UAV) as a tool for visual inspection of building facades in AEC+FM industry, *Construction Innovation,* 22(4), 1155-1170, https://10.1108/CI-07-2021-0129

[53] Nicola Moretti, JD Blanco Cadena, Antonino Mannino, Tiziana Poli, and F Re Cecconi (2021) Maintenance service optimization in smart buildings through ultrasonic sensors network, *Intelligent Buildings International*, 13(1), 4-16, https://doi.org/10.1080/17508975.2020.1765723