

Review on the Application of BIM Technology in Smart Operation and Maintenance Management of Hospitals

Hui Zhou ^{1,+}, Qiqi Lu ^{2,+}, Gongqi Zhou ^{2,+}, Xiuqin Wang ^{1,*}

¹ Shenzhen Traditional Chinese Medicine Hospital, Shenzhen, Guangdong, 518000, China

² Hubei University of Chinese Medicine, Wuhan, Hubei, 430065, China

* **Corresponding author:** Xiuqin Wang

⁺ These authors contribute equally to this article

Abstract: With the rapid development of Internet of Things (IoT) and big data technologies, the core value of Building Information Modeling (BIM) technology in the smart operation and maintenance (OM) management of hospitals has become increasingly prominent. This paper systematically reviews the global development trends of BIM technology and its current application status and challenges in hospital OM management. Domestic research primarily focuses on the design and construction stages, significantly enhancing the level of integrated and refined project management through functions such as 3D modeling, clash detection, and progress simulation. However, the operation and maintenance stage still faces challenges such as information silos, lagging resource sharing, high energy consumption, and insufficient standardization. In contrast, international research places greater emphasis on the deep integration of BIM with Facility Management (FM), actively exploring its synergistic application with cutting-edge technologies like IoT and artificial intelligence. Nevertheless, challenges remain, including insufficient integration of non-geometric information, poor system interoperability, and high implementation costs. In the future, BIM technology needs to further strengthen standardization and intelligent application, promote cross-domain integration with technologies such as digital twins and artificial intelligence, and build a management system covering the entire project lifecycle to achieve data connectivity, process optimization, and energy consumption reduction. This will provide systematic solutions for smart hospital operation and maintenance, supporting the sustainable development and digital transformation of medical buildings.

Keywords: BIM Technology; Smart Operation and Maintenance Management; Hospital Facilities; Whole Lifecycle Management; Cross-Technology Integration.

1. Research Background and Significance

In the current complex and ever-changing social context, promoting the development of hospitals towards intelligence and integration has become increasingly significant, serving as a critical part of the transformation and upgrading of the healthcare sector. With the rapid advancement of technologies such as the Internet of Things (IoT), big data, and cloud computing, coupled with the intensive introduction of a series of relevant policies at the national level, strong technical support and policy guidance have been provided for the smart construction of hospitals. Against this backdrop, utilizing Building Information Modeling (BIM) technology to promote smart operation and maintenance management in hospitals not only demonstrates broad application prospects but also exhibits diverse and innovative development characteristics.

This research topic is based on a deep concern for the numerous challenges and problems currently faced by BIM technology in the field of hospital operation and maintenance. These challenges are not only related to the maturity and application depth of the technology itself but are also closely connected to the actual needs of hospital OM management, the lack of industry standards, and the innovative capability of technology integration. Specifically, the introduction of BIM technology into hospital OM management can significantly enhance the level of integration in hospitals and promote OM management towards refinement and intelligence. With its powerful information integration

capabilities, BIM technology provides comprehensive, multi-level information support for hospital OM management, making the maintenance process more efficient and precise. However, as BIM technology becomes widely applied in hospital OM management, a series of problems have gradually emerged. These include data silos caused by information disconnects, limitations in resource sharing, suboptimal technical processing tools, high energy consumption and cost issues, and limited management efficiency due to the lack of equipment operation standards. These problems severely restrict the smooth advancement of smart OM management in hospitals. More profoundly, these challenges not only hinder the deep application of BIM technology in hospital OM management but also constrain the integrated innovation and development of BIM technology with advanced technologies such as IoT, big data, new energy-saving technologies, virtual reality, and artificial intelligence. Therefore, how to fully leverage the value of BIM technology and promote its deep integration with various advanced technologies has become an important and urgent topic to be solved.

Looking ahead, the integrated development of BIM technology with construction technology, internet technology, IoT technology, big data technology, new energy-saving technology, virtual reality technology, and artificial intelligence technology is an important path to promote the smart and green construction of hospitals. By deepening the integrated application of BIM technology and medical processes, and creating green hospital models, it can not only effectively reduce the OM management costs of hospitals and

improve OM management efficiency but also comprehensively enhance the level of facility support and promote the healthy development of the medical economy. At the same time, this will lay a solid foundation for achieving digital facility asset health management throughout the entire lifecycle and inject strong momentum into the sustainable development of the healthcare industry.

2. Domestic Research Status

Domestic theoretical research on the application of BIM technology in the smart operation and maintenance management of public hospitals originates from the actual needs of hospital OM management, promotion by policy guidance, successful demonstrations from practical cases, the impetus of interdisciplinary research, and the rapid development and widespread application of Building Information Modeling (BIM) technology in the construction industry. Since the mid-2010s, the application of BIM technology in medical buildings has begun to receive high attention from the international architecture academia and healthcare management field, becoming a hot topic for many scholars and yielding numerous research results.

In recent years, with the continuous development and application of BIM (Building Information Modeling) technology, its application in the smart medical operation and maintenance management of public hospitals has gradually become a research hotspot. Simultaneously, significant progress has been made in the smart OM management of public hospitals. BIM technology, through digital modeling and information integration, can effectively enhance the design, construction, and OM management levels and efficiency of hospital buildings, transform management models from passive to active, and integrate with IoT and artificial intelligence to elevate hospital smart OM management to a higher level. Additionally, it can reduce the energy consumption of hospital facilities and equipment, improve utilization rates, and enable visual safety management, among other benefits. These achievements not only promote the application of BIM technology in medical buildings but also provide new ideas and methods for the smart OM management of public hospitals.

2.1. Application of BIM Technology in Design

In the early stages of research, domestic scholars' research and application of BIM technology in design had matured. Proficient use of BIM technology enables information and resource sharing, constructs 3D models to improve design efficiency and quality, optimizes mechanical and electrical (M&E) design and installation procedures, provides decoration safety, and reduces costs. Scholars Wang Xianfeng and Wang Shuo (2014) relatively early explored the single application of BIM technology, focusing on its combination with Radio Frequency Identification (RFID) technology. In the initial design stage, BIM models provide the precise location and relevant information of equipment, while RFID technology enables real-time tracking and monitoring of equipment. They emphasized that it could clearly present various types of useful information through 3D visualization means while synergistically enhancing the efficiency and accuracy of equipment management processes. This laid the foundation for subsequent in-depth research on BIM technology in the hospital field [1]. Wei Shuaipeng and Li Qingda (2014) used BIM technology to construct a 3D model

of a hospital project and based on this, achieved dynamic simulation and intelligent control of the schedule, thereby making the project progress more intuitive and reducing project risks [2]. In the research of Gao Mingjie and He Qing (2016), the specific application of BIM technology in hospital engineering project management was further explored and analyzed using the Beijing Tiantan Hospital project as a case study, demonstrating the comprehensive application of BIM technology in project management. On this basis, they deeply engaged in integrated pipeline design, emphasizing that BIM technology can perform clash detection, optimize design, and transform traditional construction concepts into new concepts that keep up with the times [3]. With the continuous development of BIM technology, its application scenarios are also expanding. Scholar Yao Biwen et al. (2019) discussed the application of BIM technology in the construction of smart hospitals from a macro level, proposing that BIM technology constructing 3D models would greatly improve efficiency, enable data sharing, optimize resource allocation, and further pointed out that BIM is the information foundation supporting the construction of smart hospitals [4]. Scholar Shi Shengrong (2019) focused on the application of BIM in design management, emphasizing that BIM constructs 3D visual models, improves refinement and intelligence levels, and enhances design efficiency and quality [5]. Scholar Huang Shaopeng (2023) also, from the perspective of design management, further confirmed that BIM technology can improve design efficiency, reduce design costs, and optimize design effects [6]. As time goes by, BIM technology is being applied in more fields. Scholar Sun Zhimin et al. (2023) delved into the application of BIM technology in hospital decoration design. Utilizing the visual and parametric characteristics of BIM models makes the planning, execution, and monitoring of decoration engineering more precise and efficient, while also helping to control various costs of decoration well, laying a good foundation for subsequent construction and operation and maintenance [7].

2.2. Application of BIM Technology in Construction

In the research of scholars Gao Mingjie and He Qing (2016), starting from the basic application of BIM technology, they focused on the specific case of the Beijing Tiantan Hospital project, exploring and analyzing how BIM technology can improve the level of integration and innovate construction information technology in hospital engineering project management [3]. Scholar Liu Songqiao (2017), building on this, again focused on Beijing Tiantan Hospital, further demonstrating how BIM technology can be integrated with management processes, and using the advantages of BIM technology such as integration, digitalization, and visualization to improve project management efficiency and solve problems in the construction process in a timely manner [8]. Scholar Liu Zhao (2017), from the perspective of the overall application of hospital engineering, more broadly considered various applications of BIM technology in hospital construction, further verifying the advantages of BIM in mechanical and electrical installation [9]. Scholar Pan Junwu (2021) emphasized the use of BIM project collaboration platforms for construction management, while using BIM technology to build 3D models to track and provide timely feedback on the quality of construction materials and components, and also to achieve visual monitoring of implementation progress [10].

Many scholars have conducted in-depth research on the application and development of BIM technology in various subdivided fields. Scholar Yue Jie (2017) focused on the perspective of mechanical and electrical installation, discussing the importance and necessity of BIM technology for it, and providing strong support for subsequent operation and maintenance management [11]. Scholars Ge Yangyang and Gong Qianying (2020) proposed a new model on this basis, namely analyzing the optimization of hospital mechanical and electrical system design through the BIM-EPC collaborative management method, reducing later pipeline conflicts and hidden dangers, improving decision-making accuracy, and providing more technical and conceptual support for the innovative application of BIM technology under specific project models [12]. Scholars Ren Baojun et al. (2021) focused on outdoor pipeline network construction and introduced the integrated development of drone technology and BIM, demonstrating that BIM + drone technology solves many difficulties in construction engineering [13]. Scholar Zhu Tao (2021) also emphasized that the application of BIM technology in the design, construction, and management process of prefabricated interior decoration can achieve refined management and efficient construction of prefabricated interior decoration, improving engineering quality and construction efficiency [14]. Scholar Yang Song (2023), from the overall construction management level, discussed that BIM technology can improve on-site construction management quality, further confirming the application value of BIM technology in the construction phase [15]. In addition, scholar Zhang Yaqi (2017) further explored from the perspective of cost control. In the research, she proposed hospital engineering construction cost management based on BIM technology, demonstrating that BIM provides a basic discussion for cost control in mechanical and electrical installation. The scholar pointed out that there are still some limitations in cost aspects, such as inaccurate and unsmooth information transmission, backward management models that do not conform to the current market. However, BIM technology has potential advantages. The visual characteristics of BIM and the use of BIM to build 3D models can improve decision-making accuracy and scientificity, optimize processes, and improve engineering quality and work efficiency, laying a theoretical foundation for subsequent in-depth research on cost and budget [16]. The research of Xu Dan (2021) et al. further delved into, focusing on the optimization mechanism of BIM technology for the segmented measurement and payment process of hospital engineering funds. Through empirical research, they found that the multi-dimensional data integration capability of BIM technology can achieve dynamic verification of engineering quantities during the construction phase and visual traceability of payment basis. Through specific cases, they analyzed how BIM technology can help achieve accurate settlement during the construction process, thereby effectively controlling engineering costs. This research refines the application of BIM technology from the macro level of cost management to the micro level of the construction process, providing a quantifiable technical path for the refined control of capital flow in medical construction projects [17]. The research of scholars Xu Hanzhong and Hu Hongyuan was a more detailed discussion on the specific application of BIM technology in cost management during the hospital engineering construction phase, mainly focusing on how to control costs, emphasizing that BIM technology can

effectively solve the problem of cost overruns caused by frequent design changes and lagging engineering quantity accounting in traditional construction stages [18].

2.3. Application of BIM Technology in the Operation and Maintenance Stage

BIM technology is not yet mature in the operation and maintenance stage. From the perspective of the entire lifecycle of a building, the operation and maintenance stage occupies the longest time span, and during this period, the data to be processed is not only large in quantity but also often disordered and complex.

In terms of equipment management, scholars Wang Xianfeng and Wang Shuo (2014) researched and discussed the application of BIM integrated with RFID technology in hospital building and equipment management. BIM + RFID can promote real-time tracking and management of equipment, thereby improving the efficiency of hospital equipment management [1]. Scholar Man Tiande (2018) focused on the value of using BIM in the management of hospital logistical mechanical and electrical equipment, optimizing the management processes of equipment such as air conditioning, elevators, and water supply systems, making the management process of hospital logistical mechanical and electrical equipment standardized, standardized and quantifiable, while improving management refinement and solving the problem of information fragmentation [19]. Scholar Hu Tao (2019) focused on the integration of dynamic data and operational maintenance coordination of BIM technology in hospital mechanical and electrical equipment management, introducing technical paths such as IoT sensors, "BIM + maintenance work order" closed-loop management. Managers can intuitively understand the operating status and maintenance history of equipment, thereby formulating more scientific and reasonable maintenance plans [20]. Scholar Li Yuanbu (2019), from the perspective of the entire lifecycle, through specific practical cases, confirmed the practical value of BIM technology in the full lifecycle management of mechanical and electrical equipment, emphasizing that the application of BIM technology can help hospitals effectively control costs, reduce unnecessary expenses, and thereby improve efficiency [21], providing theoretical support and practical reference for subsequent research on intelligent operation and maintenance. The research of scholar Li Minhao (2024) et al. comprehensively sorted out and summarized the application of BIM technology in hospital facility operation and maintenance management. This review revealed the trend of BIM technology in the hospital operation and maintenance field transforming from "information visualization" to "intelligent decision-making". The application of BIM technology can improve the efficiency and quality of hospital operation and maintenance management and reduce operation and maintenance costs [22].

In terms of space resource management, the research of Yu Tao (2020) et al. introduced the concept of elasticity, proposing an optimization scheme for space resource management. Through BIM technology, it helps to achieve visual, informational, and refined management of hospital space resources, improves the utilization efficiency of space resources, and also enhances the flexibility and adaptability of space, providing innovative ideas and technical support for hospital resource management [23]. In the research of scholar Li Fang (2021) et al., taking the Affiliated Hospital of

Chengdu University of Traditional Chinese Medicine as an empirical carrier, based on the digital twin technology of BIM, it can simulate the peak and valley values of consultation room usage in real time, improving hospital resource utilization as well as hospital management level and service quality [24]. Scholar Wang Yu (2024) introduced new technology, integrating and developing BIM technology and digital twin technology innovatively. By implementing real-time monitoring of hospital logistical space resources, enabling intelligent early warning systems, and conducting optimization scheduling measures, the operational efficiency and management effectiveness of hospital logistical space management are effectively enhanced [25]. These studies provide useful references and lessons for the further application and development of BIM technology in space resource management.

In terms of emergency and safety management, scholar Yan Ben (2021) focused on the field of foundation pit monitoring and safety management in hospital construction. Using BIM technology to build a 3D foundation pit model, it displays and provides timely feedback on various types of information and engineering conditions in the foundation pit. BIM technology enables real-time analysis and early warning of foundation pit monitoring data, immediately avoiding potential accidents, timely handling of occurred accidents, and reducing losses. The application of BIM technology provides technical support for foundation pit detection, enables visual and real-time monitoring of foundation pits, and can effectively reduce the risk incidence rate [26].

In addition, scholar Liu Songqiao (2017) emphasized in his research the advantages of BIM technology in improving operation and maintenance efficiency, reducing costs, and enhancing decision support. It can solve basic problems such as incomplete, inaccurate, and difficult-to-call data [27]. Scholar Wang Jianmin (2018) also pointed out that the application of BIM in the full lifecycle management of hospitals can improve management efficiency, optimize resource allocation, and enhance building performance [28]. Scholar Xu Dingyi (2020), from the perspective of hospital logistical managers, used BIM technology to establish a precise operation and maintenance model for hospital buildings, which can improve the efficiency and quality of hospital operation and maintenance management and also promote the modernization process of hospital logistical management [29].

3. International Research Status

International research on BIM technology is more extensive, particularly in the field of integration with Facility Management (FM).

3.1. BIM and FM

3.1.1. Development and Validation of Model Systems

Rossella Marmo et al. [30] (2020) used an open standards approach to extend and validate a performance-based information model method based on the integration of BIM and FM systems from their previous research [31]. The article discusses the importance of integrating operational information into building lifecycle management, particularly applied in the FM field. BIM and FM integration was achieved by mapping a subset of the Industry Foundation Classes (IFC) schema to a relational database. A database and a new application were tested in case studies including

medical buildings. Within the same year, J. Patacas et al. [32] (2020) proposed a framework and a prototype Common Data Environment (CDE) based on open standards and existing technologies to address information management issues in the FM phase. This framework and CDE can deliver information models (i.e., Asset Information Models) from distributed data sources, thereby verifying the compliance of these information models with requirements and using them in FM (e.g., operations and maintenance). By interviewing industry experts and using grounded theory and design science methods, the researchers developed a requirements model to underpin the framework and CDE. Subsequently, they conducted a pilot demonstration in use cases focused on preventive and reactive maintenance to validate the effectiveness of the framework and CDE. The results indicate that the "BIM for FM" process can be achieved using only open standards and existing technologies. However, application validation in real projects remains to be conducted, and research limitations exist, such as the need for expert involvement in the requirements translation process. Future research directions, in addition to addressing the above limitations, include applying Semantic Web and Linked Data standards to the development and validation of AIM (Asset Information Model) and integrating other external data sources such as energy management data. E. Ergen et al. [33] (2021) researched how to formalize user feedback from office buildings and integrate it with BIM to significantly enhance FM efficiency and user experience. Currently, because relevant user feedback data is often incomplete and unstructured, making it difficult to utilize effectively, the authors developed a semantic data model to continuously collect user experience and important contextual information, including geometric data, thereby providing visualization and analysis capabilities to effectively utilize this information in FM operations. Simultaneously, the article validated the model's applicability, practicality, and usability, indicating that this method can effectively help facility managers better understand building performance and make informed maintenance, renovation, or retrofit decisions.

Rubén M. Pavón et al. [34] (2020) turned their attention to the field of educational facility management, including classroom scheduling, locker management, and the construction of 3D models of infrastructure. Taking the School of Civil Engineering at the Polytechnic University of Madrid as an example, the article proposed a BIM management system that constructs detailed 3D models based on future management needs. Utilizing the BIM Execution Plan (BEP) to determine the Level of Information (LOI) for different elements and dividing them according to management needs, the BIM model is synchronized with educational information and facility management parameters to achieve real-time information sharing and provide different levels of access permissions for administrators, students, and teachers. Within the same month, they [35] (2020), based on the special period of the global pandemic, used this BIM-FM system for epidemic prevention and control management, including personnel flow analysis, student seating arrangements, and body temperature detection, to reduce the possibility of indoor COVID-19 infection. Also using the School of Civil Engineering at the Polytechnic University of Madrid as an example, the study used mathematical methods to establish models to analyze internal personnel flow, identify congestion hotspots, and provide optimal route suggestions. In addition, the research used the BIM model to

visualize student seating arrangements, adjusted classroom capacity according to Spanish government regulations, synchronized temperature detectors with the BIM model for real-time temperature monitoring, and developed an online seat reservation system to facilitate student booking and maintain safe distances. Soon after, Rubén Muñoz Pavón et al. [36] (2021) again used the building of the Department of Civil Engineering at the Polytechnic University of Madrid as an example, detailing how to transform an old building constructed in 1969 into a smart building using BIM-FM technology and self-designed sensors with the 3D model as the management center. The article developed an intelligent platform that connects the BIM model, database, and facility management tools to integrate all management tasks, utilizes Internet of Things (IoT) technology and sensors to collect real-time data, and performs analysis and decision-making based on the data. Furthermore, this research developed smart hardware capable of connecting sensors to the intelligent platform for real-time control of lighting, heating, and air conditioning systems, and used the BIM model for energy consumption analysis, optimizing the energy system based on the analysis results to achieve energy savings and emission reduction. This provides certain reference value and feasible ideas for our research on smart operation and maintenance management of hospitals under BIM. These three papers detail the application potential of the BIM-FM system in the facility management of large public buildings and show the gradual development of a more complete system. From initial educational facility management, to epidemic prevention and control management during the COVID-19 pandemic, and then to energy management, the application scope of the BIM-FM system continues to expand, achieving significant results. In the future, the BIM-FM system is expected to integrate with other emerging technologies, such as big data and artificial intelligence, to achieve more intelligent and sustainable building management.

3.1.2. Literature Review Analysis

Kofi Asabere Bediako Asare et al. [37] (2021) focused on large capital projects. After conducting a comprehensive literature review on the application of BIM in FM, they found that research in this field mainly concentrates on the technical and process levels, with less attention paid to people and organizations, and a lack of practical cases of successful integration of the two. Research on the technical process level mainly focuses on four major areas: information management, building performance and energy management, maintenance management, and renovation and retrofit. The article suggests that future research should pay more attention to the initiation stage of BIM-FM integration, such as strategic planning, value realization, and initiation decisions, emphasizing the importance of developing a strategic planning framework for BIM-FM application suitable for large capital projects, value realization evaluation indicators, and technology acceptance models. Wang Tao et al. [38] (2022) used bibliometric analysis to explore the knowledge system in the field of BIM-based FM, revealing the research hotspots and future trends of BIM-FM. The article divides this knowledge system into five main clusters, showing an evolutionary trend according to different periods, gradually expanding from model construction frameworks to implementation, system integration, and smart buildings. Ma P et al. [39] (2022) systematically reviewed the changing role of BIM-assisted facility management in the post-pandemic era, discussing the current challenges and opportunities of BIM in facility

management, and how the COVID-19 pandemic accelerated the transformation of this technology. The study found that BIM technology plays an increasingly important role in the post-pandemic era, such as improving space utilization efficiency, optimizing operation and maintenance processes, and strengthening risk management, allowing FM managers to respond to the pandemic with greater ease. Gabriela Alves Tenório de Moraes et al. [40] (2024) combined scientometric analysis and systematic literature review to analyze the application of BIM in facility management, operations, and maintenance, indicating that the application scope of BIM in FM is gradually expanding, including user comfort, data management, safety monitoring, facility management, operations, and maintenance, and supports the integration of emerging technologies with BIM.

In an article published in November 2022 by Rodrigo Pedral Sampaio et al. [41] (2022), the authors reviewed the latest research progress in the application of artificial intelligence technology to FM under BIM. A systematic analysis of relevant literature between 2012 and 2021 found that research in this field shows a rapid growth trend. When summarizing future directions, the article categorized them into six major categories: data and system integration, predictive models, automatic as-built/classification, Internet of Things (IoT), energy management, and augmented/virtual reality. The authors stated that traditionally, FM is separated from architectural design and construction in the building lifecycle, leading to inefficiency problems. With the rise of BIM technology, its rich building element information brings unlimited opportunities for FM. Integrating information and managing processes significantly improve efficiency. A few months later, they [42] (2023/1) further focused on studying the impact of the digital transformation of FM (facility management), proposing the integration of technologies such as BIM, IoT, and AI with FM to improve efficiency and address new development challenges and difficulties in hospitals. The suggested feasible future research directions largely overlap with those in the previous article. Research on BIM as a platform for building information integration and sharing, integrated with IoT and AI technologies to achieve intelligent operation and maintenance management, reduce costs and increase efficiency, and improve safety, is still in its infancy. The article indicates that current BIM management models lack non-geometric information, such as installation date and warranty instructions, which limits the intelligence of FM to a certain extent. In addition, high technology application costs, integration issues between BIM and FM systems, and the lack of BIM models for existing buildings are also problems to be solved. Therefore, open standard data models and protocols, as well as efficient and feasible reality capture technologies, will be one of the ideas to break the deadlock, which is consistent with the thinking of the scholars mentioned earlier who focused on model development and validation. Then, in May of that year, Rodrigo Pedral Sampaio et al. [43] (2023/5) used hospital buildings as the application scenario and the post-COVID-19 pandemic as the starting point to discuss the legacy left by FM teams and how digital transformation can improve the operation and maintenance management of infrastructure in hospital facilities. As a special type of building, hospitals have a high deterioration rate due to their high usage rate, being open 24 hours a day, all year round, making the role of FM crucial for them. The article predicts that FM will grow at an annual rate of 5%, meaning the industry will develop rapidly worldwide, and

Industry 4.0 will also be a major driver. Similar to the previous two articles, the authors remain optimistic about the future prospects of digital transformation and building intelligence, supporting the complementary relationship between relevant technologies and FM. However, this article also focused on innovative sustainable communities and smart community concepts. Additionally, it is worth noting that compared to the issues focused on in the January 2023 article, this article also emphasized the predicament of the lack of BIM-skilled talent and again focused on human factors in future direction suggestions. Besides real-time interaction, digital twins, and standardization, it raised the issue of end-user (infrastructure operation and maintenance personnel) access rights to BIM and its feasibility.

3.2. BIM and Infrastructure Operation and Maintenance Management

Dania K. Abideen et al. [44] (2022) evaluated the extent of BIM application in the building operation and maintenance (O&M) phase, indicating that BIM is mainly integrated under seven functions: Information Management (IM), Advanced Technology (AT), Maintenance and Asset Management (MAM), Indoor Management (IM) [Note: This appears to be a repeat; likely a different IM was intended, perhaps 'Inventory Management' or similar, but the source says Indoor Management], Performance Assessment (PA), Visualization (V), and Lean Management (LM). Among these, most BIM integrations belong to the Information Management function, while Lean Management is the least. The article states that current research mainly focuses on institutional and infrastructure types, while residential, industrial, and commercial buildings are relatively insufficient. Jorge Jerez Cepa et al. [45] (2023) also focused on the current status of the BIM method in infrastructure operation and maintenance, but their research approach differs from the former. The article states that although current BIM is widely used in the construction industry, its application in infrastructure operation and maintenance management is very limited. The authors support the integration of other emerging technologies (IoT, big data, blockchain, geographic information systems, etc.) and analyzed the application of BIM in the operation and maintenance of different infrastructure types, exploring its potential in railways and other fields. The article points out that BIM is expanding to various stages of project construction and multiple building types, and together with other technologies, it is becoming a main driving force for smart construction. However, challenges such as huge data volume, lack of standardization, poor interoperability, and the need for professional skills have become unavoidable issues to be solved, which coincide with the key obstacles mentioned in the article by Bilal Manzoor et al. [46] (2021).

3.3. BIM Scenario Applications

3.3.1. Comprehensive Literature Analysis

Behzad Abbasnejad et al. [47] (2020) reviewed the literature from 2004 to July 2019 on the adoption and implementation of BIM in AEC (Architecture, Engineering, and Construction) companies. The study shows that although the potential benefits of BIM are significant, there are still many challenges in comprehensive implementation, partly due to the lack of clear implementation guidelines and the inapplicability of organizational business structures. Therefore, the article proposed a BIM implementation

framework. This framework consists of seven components: Strategic Initiatives, Learning Capability, Cultural Readiness, IT Availability and Knowledge Sharing Capability, Network Relationships, Change Management, and Process and Performance Management. Simultaneously, the article identified 27 key factors promoting BIM adoption and implementation, classifying them into the above seven parts. Training and education, top management support, BIM implementation plan, and BIM expertise are the most frequently cited promoting factors.

3.3.2. Constructing Systems or Frameworks for Special Problems

Chih-Lung Lin et al. [48] (2021) explored how to use BIM and Multi-Criteria Decision Making (MCDM) methods to evaluate and optimize the management of smart hospitals during the COVID-19 pandemic. The study first analyzed the challenges faced by smart hospitals during the pandemic, such as insufficient negative pressure wards and backward medical information systems. Then, using the Analytic Hierarchy Process (AHP) method, it established a smart hospital evaluation system containing five main evaluation indicators: Internet of Things (IoT), Cyber-Physical Systems (CPS), Artificial Intelligence (AI), Management Information Systems (MIS), and Service Technology Innovation. The article states that BIM technology can help smart hospitals with asset management, optimize space utilization, monitor the epidemic in real-time, etc., improving the ability to respond to public health emergencies. The research results indicate that the most important are the functional indicators related to end-users, such as the network core function of IoT, the deep learning of AI, and the special network technology of CPS.

Emiliya Suprun et al. [49] (2022) believe that the key to successful BIM adoption and implementation lies in the accuracy of the asset information stored in the BIM model, especially for existing assets. However, in fact, asset management information is often unsatisfactory, presenting as inaccurate, incomplete, outdated, duplicate, or missing. With the advancement of 3D laser scanning technology, capturing the accurate as-is conditions of existing buildings has become possible, thus providing a feasible direction for problem-solving. The potential advantages of shifting from "as-designed" BIM to "as-built" BIM are also becoming more convincing and expected. Focusing on a case study of a water treatment plant in southeastern Australia, this paper identified the cost and benefit elements of the Scan-to-BIM process and developed a stakeholder mapping for both, helping asset owners and relevant parties better understand the pros and cons of the "Scan-to-BIM" process. Simultaneously, the article determined that the needs of the project and assets will determine the impact of different Levels of Development (LOD) and Levels of Information (LOI) on BIM application. To help water facility owners and stakeholders use Scan-to-BIM technology to realize the value of existing facilities and improve asset management and operational efficiency, the article finally proposed a reliable framework for reference.

3.3.3. Promoting BIM Application Levels in Different Regions or for Different Objects

The implementation of BIM Level 2 in the UK construction industry has grown significantly over the past decade, especially after the UK government mandated the use of BIM in all public projects in 2016. However, while large enterprises prioritize BIM implementation, small and medium-sized enterprises (SMEs) lag far behind in adoption,

and this lag will cause SMEs to fall into a competitive disadvantage in public projects. Khaled Abu Awwad et al. [50] (2022) explored the key success factors affecting the implementation of BIM Level 2 in SMEs in the UK construction industry. They classified these factors into four categories: human factors, organizational factors, process factors, and external factors, and evaluated their importance in the implementation process, providing valuable advice for the successful implementation of BIM in SMEs. Seda Tan et al. [51] (2022) provided a quantitative model of key success factors and their impact levels for the successful implementation of BIM by construction companies in the Turkish construction industry (and other developing countries), in order to provide a reference for the rapid and effective implementation of BIM in the Turkish construction industry, where BIM application is relatively backward. The research results show that the perception of technical benefits has the greatest impact on BIM implementation, followed by organizational readiness and competitive advantage, while management's motivation for BIM has the least impact. Thi-Thao-Nguyen Nguyen et al. [52] (2024) explored the key factors affecting BIM application in Vietnamese construction enterprises and their interrelationships. By evaluating 32 BIM application factors in the Vietnamese construction industry, combined with a mixed questionnaire survey using convenience sampling, they used exploratory factor analysis and partial least squares structural equation modeling (PLS-SEM) techniques to identify six factor structures that have a significant impact on BIM application in construction enterprises. Among them, human resources and management, technical feasibility, and company business vision have the most significant impact on managers' evaluation of BIM factors.

3.4. BIM and FM

International scholars have conducted detailed analyses on the integration of BIM and FM. Overall, research mainly focuses on technical integration, information management, and process optimization. This is because BIM technology can effectively integrate building information and improve the efficiency and accuracy of facility management. However, existing research mostly focuses on the technical and process levels, with less attention paid to human and organizational factors, leading to certain obstacles in the promotion and implementation of BIM in practical applications. The lack of non-geometric information in BIM models (such as installation date, warranty instructions, etc.) limits its intelligent application in facility management; the integration problem between BIM and FM systems, especially in the case of existing buildings lacking BIM models, leads to high implementation costs; the complexity of BIM technology and its reliance on professional skills pose great challenges for small and medium-sized enterprises and some developing countries in applying BIM. The existence of these three phenomena also provides direction and guidance for more subsequent research. In addition, some scholars have pointed out that the application of BIM in infrastructure operation and maintenance is still in its infancy, especially in fields such as railways and energy, where the potential of BIM has not been fully utilized. Some scholars have also pointed out that the integration of BIM with other emerging technologies (such as IoT, artificial intelligence, big data) is an important future direction, but the problems of data standardization and poor interoperability need to be solved urgently.

Firstly, the standardization and interoperability of BIM technology is a major problem currently faced. Due to the inconsistency of data formats between different systems and platforms, information sharing and integration are difficult. Therefore, it is necessary to strengthen the research and promotion of open standards and improve the compatibility of BIM models. Secondly, the intelligent application capability of BIM technology needs to be improved. Although BIM performs well in information management and visualization, it still needs further research and development in advanced functions such as predictive maintenance and energy optimization. Therefore, it is necessary to combine artificial intelligence and big data technology to improve the intelligent level of BIM. Finally, the application mode of BIM technology needs further exploration and innovation. At present, most applications still remain in the design and construction stages, lacking in-depth exploration of the operation and maintenance stage. Therefore, it is necessary to combine the current situation to develop BIM application modes suitable for different scenarios and promote the comprehensive application of BIM technology in facility management.

4. Commentary

Through a comprehensive analysis of domestic research literature on BIM technology, it can be seen that current research mainly focuses on the design and construction stages, with relatively rich results. Scholars generally agree on the significant advantages of BIM technology in terms of integration, digitalization, and visualization, which is particularly helpful for achieving refined management of construction projects such as hospitals, improving performance in cost, quality, efficiency, and energy utilization, and providing an information collaboration foundation for full lifecycle management. In addition, BIM also plays a positive role in improving process transparency, avoiding construction risks, and optimizing equipment operation and maintenance. However, BIM technology still faces challenges in practical application, such as poor information flow, tool limitations, insufficient resource sharing, relatively high energy consumption, and lagging management models. To this end, domestic scholars are actively exploring a multi-technology integration path with BIM 3D models and visualization platforms as the core, combined with RFID, IoT, big data, cloud computing, and energy-saving technologies, aiming to break down information barriers and promote the development of intelligence and refined management. In comparison, international research focuses more on the integrated application of BIM in the field of construction and facility management (FM), focusing on technical integration, information management, and process optimization, but research at the personnel and organizational levels is still insufficient. In addition, problems such as the lack of non-geometric information in BIM, the high cost of modeling existing buildings, and the strong reliance on professional ability limit its promotion in facility management. In the future, the integration of BIM with technologies such as IoT, artificial intelligence, and big data is regarded as an important direction, but data standardization and system interoperability remain bottlenecks that need to be broken through. Overall, the development of BIM technology needs to focus on three aspects: first promoting the construction of data standards and interoperability capabilities. Second strengthening the

research and development of advanced functions such as intelligent prediction and energy optimization in hospitals. Third innovating the application mode in the hospital operation and maintenance stage. In the future, we should continue to promote the integration of BIM and emerging technologies, explore application paths that meet the actual needs of hospital management, and fully release its potential in construction and facility management.

Acknowledgments

This work is supported by the Special Fund for the Construction of High-level Hospitals in Shenzhen.

References

- [1] Wang, X., & Wang, S. (2014). Application of BIM Integrated with Radio Frequency Technology in Hospital Building and Equipment Management. *Computer Knowledge and Technology*, 10(18), 4143-4146+4157.
- [2] Wei, S., & Li, Q. (2014). Development and Application of BIM Technology in Schedule Management of Luhe Hospital Project. *Construction Technology*, 43(S2), 577-579.
- [3] Gao, M., & He, Q. (2016). Application of BIM Technology in the Project Management of Beijing Tiantan Hospital Project. *Journal of Information Technology in Civil Engineering and Architecture*, 8(02), 38-43.
- [4] Yao, B., Wei, G., Shao, M., et al. (2019). Application and Reflection on BIM Technology in the Construction of Smart Hospitals. *Intelligent Building*, (05), 51-56.
- [5] Shi, S. (2019). BIM Technology Assisting in Hospital Architectural Design Management. *Chinese Hospital Architecture & Equipment*, 20(10), 38-40.
- [6] Huang, S. (2023). Analysis of Design Management Effects in the Second Phase of H Hospital Based on BIM Technology [Master's thesis, Kunming University of Science and Technology].
- [7] Sun, Z., Cao, L., Zhang, W., et al. (2023). Management Method for Hospital Building Decoration Engineering Based on BIM Technology. *China Building Decoration & Renovation*, (22), 89-91.
- [8] Liu, S., Tu, H., & Wu, Z. (2017). Exploration of BIM Technology Application in the Construction Management of Beijing Tiantan Hospital Relocation Project. *China Engineering Consulting*, (06), 58-60.
- [9] Liu, Z. (2017). Application of BIM in Hospital Engineering [Master's thesis, Tianjin University].
- [10] Pan, J., Du, Z., & Lu, J. (2021). Application of BIM Technology in Hospital Building Construction Management. *Low Temperature Architecture Technology*, 43(04), 147-149+153.
- [11] Yue, J. (2017). Analysis of the Application Value of BIM Technology in Mechanical and Electrical Installation of Medical Buildings. *World Latest Medicine Information*, 17(01), 137.
- [12] Ge, Y., & Gong, Q. (2020). Discussion on Mechanical and Electrical Design Management of EPC Mode Hospital Project Based on BIM Technology. *Building Technology Development*, 47(08), 48-49.
- [13] Ren, B., Zhang, F., Liu, J., et al. (2021). Application of BIM + UAV Assisted Management Technology in Large Hospital Outdoor Pipeline Network Engineering. *Installation*, (04), 15-17.
- [14] Zhu, T., Zhang, W., & Zhang, C. (2021). Application and Construction Management of Hospital Prefabricated Interior Decoration Based on BIM Technology—A Case Study of the Prefabricated Interior Decoration Project of the Comprehensive Ward Building of Zhejiang Provincial People's Hospital. *Chinese Hospital Architecture & Equipment*, 22(05), 27-29.
- [15] Yang, S. (2023). The Enhancing Effect of BIM Technology-Based Site Management on Construction Quality—A Case Study of the East Hospital Construction Project of Beijing Chaoyang Hospital Affiliated to Capital Medical University. *Real Estate World*, (16), 100-102.
- [16] Zhang, Y. (2017). Applied Research on Construction Cost Management of Hospital Engineering Projects Based on BIM Technology [Master's thesis, Beijing University of Civil Engineering and Architecture].
- [17] Xu, D., Zhang, Y., Zhao, Y., et al. (2021). Research on Construction Process Settlement Management of Hospital Projects Based on BIM Technology. *Engineering Economy*, 31(12), 47-50. DOI:10.19298/j.cnki.1672-2442.202112047.
- [18] Xu, H., & Hu, H. (2023). Application of BIM Technology in Cost Management during the Construction Phase of Hospital Projects. *Building Technology Development*, 50(11), 117-119.
- [19] Man, T. (2018). Application of BIM Technology in the Management of Hospital Logistics Mechanical and Electrical Equipment. *China Health Industry*, 15(31), 84-86.
- [20] Hu, T. (2019). Exploration of the Application of BIM Technology in Hospital Logistics Mechanical and Electrical Equipment Management. *China Equipment Engineering*, (13), 28-29.
- [21] Li, Y. (2019). Application of BIM Technology in Hospital Logistics Mechanical and Electrical Equipment Management. *New Technology & New Products of China*, (22), 114-115.
- [22] Li, M., Liu, Y., Zhu, Y., et al. (2024). A Review of BIM Application Research in Hospital Facility Operation and Maintenance Management. *Chinese Hospital Architecture & Equipment*, 25(09), 52-55.
- [23] Yu, T., Haijirete, X., Li, Y., et al. (2020). Research on Hospital Space Resource Management Based on BIM Technology and Elastic Concept. *Construction Economy*, 41(06), 45-48.
- [24] Li, F., Qiu, B., Li, L., et al. (2021). Exploration of Intelligent Management of Hospital Building Space Based on BIM Technology—A Case Study of the Affiliated Hospital of Chengdu University of Traditional Chinese Medicine. *Chinese Hospital Architecture & Equipment*, 22(09), 89-92.
- [25] Wang, Y., Song, D., Wang, X., et al. (2024). Application Practice and Exploration of BIM-Based Digital Twin Technology in Hospital Logistics Space Management. *Chinese Hospital Architecture & Equipment*, 25(06), 43-49.
- [26] Yan, B. (2021). Application of BIM Technology in Safety Management of Hospital Construction Foundation Pit Monitoring. *Green Building*, 13(05), 96-98.
- [27] Liu, S., Tu, H., & Liu, Y. (2017). Research on the Application of BIM Technology in the Operation and Maintenance Management of Beijing Tiantan Hospital Relocation Project. *China Engineering Consulting*, (11), 55-57.
- [28] Wang, J. (2018, January 29). Research on the Construction Process and Operation and Maintenance Management of Hospital Buildings Based on BIM Technology [Final Report]. Zhejiang Provincial Academy of Building Research & Design Co., Ltd., Zhejiang Province, China.
- [29] Xu, D. (2020). Research on Precise Clinical Pathway for Hospital Building Operation and Maintenance Based on BIM. *Chinese Hospital Architecture & Equipment*, 21(02), 99-101.

- [30] Marmo R, Polverino F, Nicolella M, et al. Building performance and maintenance information model based on IFC schema[J]. *Automation in Construction*, 2020, 118: 103275.
- [31] Marmo R, Nicolella M, Polverino F, et al. A methodology for a performance information model to support facility management[J]. *Sustainability*, 2019, 11(24): 7007.
- [32] Patacas J, Dawood N, Kassem M. BIM for facilities management: A framework and a common data environment using open standards[J]. *Automation in Construction*, 2020, 120: 103366.
- [33] Ergen E, Kula B, Guven G, et al. Formalization of occupant feedback and integration with BIM in office buildings[J]. *Journal of computing in civil engineering*, 2021, 35(1): 04020055.
- [34] Pavón R M, Arcos Alvarez A A, Alberti M G. BIM-based educational and facility management of large university venues[J]. *Applied Sciences*, 2020, 10(22): 7976.
- [35] Pavón R M, Arcos Alvarez A A, Alberti M G. Possibilities of BIM-FM for the Management of COVID in Public Buildings[J]. *Sustainability*, 2020, 12(23): 9974.
- [36] Pavón R M, Alberti M G, Álvarez A A A, et al. Use of BIM-FM to transform large conventional public buildings into efficient and smart sustainable buildings[J]. *Energies*, 2021, 14(11): 3127.
- [37] Asare K A B, Liu R, Anumba C J. Building information modeling to support facilities management of large capital projects: a critical review[J]. *Facilities*, 2022, 40(3/4): 176-197.
- [38] Tao W, Shah A A, Peng C A. Exploring a body of knowledge for promoting the building information model for facility management[J]. *Ain Shams Engineering Journal*, 2022, 13(4): 176-197.
- [39] Ma P, Chan I Y S. The changing role of BIM-facilitated facilities management in the post-COVID era: A systematic literature review[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2022, 1101(3): 032024.
- [40] Morais G A T, Almeida Filho A T, Palha R P. BIM para gerenciamento, operação e manutenção de instalações: revisão científica e sistemática[J]. *Ambiente Construído*, 2024, 24: e131575.
- [41] Pedral Sampaio R, Aguiar Costa A, Flores-Colen I. A systematic review of artificial intelligence applied to facility management in the building information modeling context and future research directions[J]. *Buildings*, 2022, 12(11): 1939.
- [42] Pedral Sampaio R, Aguiar Costa A, Flores-Colen I. A discussion of digital transition impact on facility management of hospital buildings[J]. *Facilities*, 2023, 41(5/6): 389-406.
- [43] Sampaio R P, Costa A A, Flores-Colen I. Discussion of digital transition impact on the facility management sector applied to healthcare buildings[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2023, 1176(1): 012014.
- [44] Abideen D K, Yunusa-Kaltungo A, Manu P, et al. A systematic review of the extent to which BIM is integrated into operation and maintenance[J]. *Sustainability*, 2022, 14(14): 8692.
- [45] Cepa J J, Pavón R M, Alberti M G, et al. A Review on the Implementation of the BIM Methodology in the Operation Maintenance and Transport Infrastructure[J]. *Applied Sciences*, 2023, 13(5): 3176.
- [46] Manzoor B, Othman I, Gardezi S S S, et al. BIM-based research framework for sustainable building projects: a strategy for mitigating BIM implementation barriers[J]. *Applied Sciences*, 2021, 11(12): 5397.
- [47] Abbasnejad B, Nepal M P, Ahankoob A, et al. Building Information Modelling (BIM) adoption and implementation enablers in AEC firms: A systematic literature review[J]. *Architectural Engineering and design management*, 2021, 17(5-6): 411-433.
- [48] Lin C L, Chen J K C, Ho H H. BIM for smart hospital management during COVID-19 Using MCDM[J]. *Sustainability*, 2021, 13(11): 6181.
- [49] Suprun E, Mostafa S, Stewart R A, et al. Digitisation of existing water facilities: A framework for realising the value of scan-to-BIM[J]. *Sustainability*, 2022, 14(10): 6142.
- [50] Awwad K A, Shibani A, Ghostin M. Exploring the critical success factors influencing BIM level 2 implementation in the UK construction industry: the case of SMEs[J]. *International journal of construction management*, 2022, 22(10): 1894-1901.
- [51] Tan S, Gumusburun Ayalp G, Tel M Z, et al. Modeling the critical success factors for BIM implementation in developing countries: Sampling the Turkish AEC industry[J]. *Sustainability*, 2022, 14(15): 9537.
- [52] Nguyen T T N, Do S T, Nguyen V T, et al. Interrelationships among enabling factors for BIM adoption in construction enterprises[J]. *Engineering, Construction and Architectural Management*, 2024, 31(2): 891-918.