A Review of BIM-based Building Operations and Maintenance Technologies and Applications (Postprint)

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Abstract

The operations and maintenance phase accounts for over 90% of the time and more than 80% of the costs in a building' s lifecycle; therefore, pursuing efficient operations and maintenance management methods holds significant importance. This paper elaborates on the advantages of BIM application in building operations and maintenance, discusses and analyzes BIM-based operations and maintenance management methods from both technological and application perspectives, examines the current technical challenges, and outlines future research development trends.

Full Text

A Review of BIM-Based Building Operation and Maintenance Technologies and Applications

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Abstract

The operation and maintenance phase accounts for over 90% of a building' s lifecycle duration and more than 80% of its total cost, making the pursuit of efficient operation and maintenance management critically important. This paper discusses the advantages of applying BIM in building operation and maintenance, analyzes BIM-based operation and maintenance management methods from both technical and application perspectives, examines current technical challenges, and outlines future research trends.

Keywords: Building Information Modeling (BIM); operation and maintenance management; application status and technical analysis; research trends

1 Advantages of BIM Application in Operation and Maintenance

Traditional management based on paper drawings and 2D platforms suffers from information loss during handover, low management efficiency, and poor visualization, leading to wasted time and frequent errors in practice. Consequently, researchers have increasingly focused on transforming conventional operation and maintenance models to seek more efficient management approaches. Practice has demonstrated that BIM technology enables effective energy savings, cost reduction, pollution mitigation, and efficiency improvements throughout the entire project lifecycle—including design, construction, and operation and maintenance phases—thereby enhancing the integration of building management [31]. BIM technology has progressively extended its application from architectural design and construction into the operation and maintenance phase [1].

While review articles on BIM operation and maintenance applications exist both domestically and internationally, and Hu Zhenzhong et al. [2] have provided a relatively comprehensive summary of BIM applications in operation and maintenance management, these works lack discussion of specific functional implementations and technical issues, and their summaries of core platform construction technologies remain incomplete. Unlike these previous reviews, this paper summarizes the advantages of integrating BIM with operation and maintenance management, analyzes the technical challenges of applying BIM to operation and maintenance, and presents a synthesis of existing research findings on BIM applications in operation and maintenance management.

Applying BIM technology to operation and maintenance management enables integrated information sharing and visualized equipment management [3]. BIM' s 3D visual models facilitate precise geometric representation of building components and their spatial positioning, creating easily modifiable visual components for effective space management. They enable rapid generation of operation and maintenance databases for faster and more efficient information sharing, saving time and costs. These models can be utilized for building performance simulation and commissioning, predicting energy consumption performance and calculating lifecycle costs. Model data can be applied to simulation tools, with constructed information used for building model optimization and renovation. BIM also supports novel applications such as route planning for maintenance personnel path optimization or intelligent emergency evacuation [24].

[Figure 1: see original paper] Comparison of various management methods

As shown in Figure 1, compared with traditional paper-based manual management, BIM-based comprehensive management improves efficiency across design, construction, and operation and maintenance phases while reducing information loss during phase handovers. BIM' s 3D models contain more comprehensive information, helping construction and management personnel better understand architectural designs. Compared with semi-automated management based on 2D platforms, BIM-based comprehensive management reduces the time required for model conversion from design to operation and maintenance phases, and its 3D visualization approach enhances operation and maintenance efficiency [22].

Among the advantages of BIM-operation and maintenance integration, accurate space management, efficient database sources, and preventive maintenance using BIM data constitute the most significant benefits [24].

2 Core Technologies for BIM-Based Building Operation and Maintenance Management

BIM-based operation and maintenance management represents a novel three-dimensional management approach. Built upon BIM as a critical carrier for information integration and presentation, it enables intuitive visualization of building information and visualized control of equipment operation, thereby effectively improving operation and maintenance efficiency and intelligent management levels.

We categorize the core technologies for BIM-based building operation and maintenance management into three aspects: (1) BIM models for operation and maintenance management; (2) cyber-physical system integration technology; and (3) platform development methods.

2.1 BIM Models for Operation and Maintenance Management

Models form the foundation of operation and maintenance management systems. Key considerations include how to construct models, what requirements models should satisfy, and how to customize and extend models. When building systems, missing models require custom definition and extension. Currently, three primary methods exist for BIM model extension [4]: extension based on IFC Proxy entities, extension based on adding entity types, and extension based on property sets.

The IFC Proxy entity extension method utilizes IFC Proxy entities to extend information undefined in the original model system. Zhou Liang et al. [5] extended GIS equipment from power transmission and transformation projects into electrical equipment models according to IFC standards, enabling effective information exchange and sharing. Yu K et al. [6] introduced equipment management classes and computer-integrated facility management systems.

The entity type extension method involves expansion and updating of the model' s native definitions. Yu Fangqiang et al. [7] documented changes and developments in core modules across various IFC standard versions since the release of IFC2x. Building SMART [8] extended the IFC standard by establishing the new IFC4 standard.

The property set extension method expands attributes with information description capabilities. Liu Zhaoqiu et al. [9] extended missing information in the IFC standard' s structural product model from three aspects—geometric information models, load information models, and analysis information models—thereby improving the basic framework of the IFC standard' s structural information model. Rio J et al. [10] discussed current limitations of IFC models and proposed methods for extending special property sets for various sensors based on generic sensor property sets.

2.2 Integration of Virtual BIM Models and Building Physical Systems

Current mainstream BIM technology only supports description of static information such as geometric data, spatial positions, and relationships, which no longer satisfies increasingly complex operation and maintenance management requirements. How to achieve dynamic interaction between BIM' s static information models and building physical models has become an urgent problem.

Cyber-Physical Systems (CPS) represent a multi-dimensional complex system integrating computation, networking, and physical environments. Through organic fusion and deep collaboration of 3C (Computation, Communication, Control) technologies, CPS enables real-time perception, dynamic control, and information services for large-scale engineering systems [11]. CPS uses digital graphics as a medium connecting physical and geometric attributes, achieving "data attached to graphics, graphics containing data" [12]. It consolidates originally independently operated and field-controlled equipment onto a unified management platform using technologies like RFID, enabling both real-time monitoring of equipment operation status and remote control.

2.3 Platform Development Methods

Constructing operation and maintenance platforms requires solving problems such as bidirectional model data transmission, 3D model display, and data binding [13]. The platform' s 3D model visualization function needs to convert information completely into 3D models and visually display component positions and relationship information. Currently, model display primarily relies on software such as AutoCAD, OpenGL, and Direct3D.

Mobile handheld terminals represent an effective approach for platform information interaction, already applied in BIM construction phases. For example, Guangzhou Metro construction used "work order"systems to distribute construction information to workers via mobile apps while feeding construction progress back into the system. In the operation and maintenance phase, mobile terminals are mainly applied in equipment inspection roaming, scanning devices to display basic information [14], and equipment repair reporting [15].

2.4 Summary Analysis

[Figure 3: see original paper] Research focus on core technologies

In 1975, Professor Chuck Eastman of Georgia Tech, the "Father of BIM," proposed the BIM concept, which has since profoundly impacted the construction industry. This paper analyzes the core technical issues requiring resolution in building BIM-based operation and maintenance management systems and summarizes existing research findings. As shown in Figure 3, current research primarily focuses on BIM-based operation and maintenance platform construction and BIM model extension, while few studies address dynamic information interaction between BIM static information models and building equipment.

3 Application Status

3.1 Application Function Classification and Definition

BIM technology' s visualization and coordination capabilities enable integration of data with 3D models, effectively promoting information interaction and improving integration and compatibility between building information and operation and maintenance systems. We classify operation and maintenance management system functions into seven categories, as shown in Table 1 :

Table 1 Functions and Applications

Function Type	Description	Application Examples
Space Management	Management of spaces and personnel/equipment within them, including personnel management, space planning and allocation, and equipment location management.	(1) Urban rail transit construction (2) Manchester City Hall building

Function Type	Description	Application Examples
Information Management	Management of all building information and new information generated during operation, including asset management and equipment information management.	(1) BIM system for asset management (2) Hospital integrated maintenance monitoring (3) Knowledge management (4) Electronic Document Management System (EDMS)
Equipment Supervision	Monitoring of equipment operation and control adjustment of operational status, including equipment information supervision and real-time equipment control.	(1) BIM applied to equipment operation status supervision (2) Applied to real-time equipment control [3][16][17][27][31]
Safety Management	Safety issue investigation and emergency incident feedback management, including security management, fire protection management, and concealed works management.	(1) Building Automation System (BAS) [19][23] (1) Sydney Opera House (2) Energy Management System (EMS) (3) Energy analysis and sustainability
Energy Consumption Management	Display, analysis, and remote control of building energy consumption for energy-saving purposes.	(1) USC construction project (2) Xavier University construction project [20][21][28][29]

Function Type	Description	Application Examples
Change Management	Management of personnel, operations, and equipment flow during changes based on real-time information to avoid operational conflicts.	
Other Functions	Provision of building space, structure, and quantity information for other functional requirements.	(1) Automated cost estimation (2) Computerized Maintenance Management System (CMMS)

3.2 Application Status

BIM-based visualized space management enables systematic and information-based management of personnel and spaces. Personnel location management allows real-time monitoring of personnel position changes within buildings. Campus operation and maintenance systems [16] can track campus patrol personnel positions through video surveillance, displaying information in real-time on the platform. Space planning and allocation [3] involves optimal layout of functional modules and merchant locations within buildings. Equipment location management enables monitoring of mobile equipment positions such as elevators and vehicles [17].

Information management primarily includes asset management and equipment information management. By injecting information into RFID asset tag chips and combining with 3D virtual BIM technology, precise asset location and rapid information retrieval can be achieved. Equipment information management covers maintenance and cleaning cycles, waste disposal, and recycling information. Rail transit equipment maintenance systems have transformed traditional repair reporting methods that required manual fault point inspection and manual database entry. The designed repair platform includes two methods: handheld mobile device reporting by inspection personnel and real-time platform monitoring reporting [18], improving efficiency and reducing errors in intermediate steps.

Equipment supervision includes equipment information supervision and real-time equipment control. Equipment information supervision enables monitoring of equipment operation status to ensure timely fault detection. BIM-based management systems integrate equipment search, review, and location functions.

Operation and maintenance management systems combining BIM with AR and other human-computer interaction technologies can intuitively display equipment operation status on BIM models and enable visualized real-time equipment control through the BIM operation and maintenance platform.

Security management involves managing and controlling all personnel, objects, and environmental states within the system, primarily applied in military bases, critical equipment rooms, banks, campuses, main roads, and other locations with high monitoring requirements. For example, BIM-based fire protection management systems effectively improve operation and maintenance efficiency and ensure normal operation of all fire protection equipment [23]; BIM-based operation and maintenance systems can visually represent concealed works—traditionally managed manually—in 3D form, displaying various pipelines in 3D models and enabling pipeline information queries through model selection.

Energy consumption management involves intelligent energy-saving management of buildings. Electricity monitoring systems collect power consumption information in the management system by installing sensor-enabled meters and automatically perform statistical analysis of energy consumption to promptly identify anomalies. Water monitoring systems display building water network location information clearly on BIM operation and maintenance platforms through meter monitoring, enabling effective water balance judgment [20][21]. Overall, building energy consumption management systems integrate BIM with IoT, sensors, controllers, and other technologies to monitor and analyze building energy usage and control energy-consuming equipment operation, reducing costs caused by high energy consumption under traditional operation and management.

[Figure 4: see original paper] Application proportion

Reviewing and summarizing literature from various sources reveals that current BIM technology applications in building operation and maintenance management primarily focus on equipment supervision (as shown in Figure 4). Effective equipment management can optimize benefits for building owners. How to continue optimizing in traditional advantage areas while expanding BIM application scope in emerging fields represents our future research direction.

4 Analysis of Technical Bottlenecks in BIM-Based Operation and Maintenance

BIM technology provides new collaborative methods for operation and maintenance management but also generates certain problems. With increasing demands for building operation and maintenance management, core issues requiring future attention include how to achieve deeper information acquisition, interaction, and visualized presentation.

(1) **Operation and maintenance platform information processing and big data analytics.** BIM visualized monitoring platforms generate massive data about buildings and equipment operation, imposing requirements

on host computers for large-capacity storage, rapid processing, and accurate analysis. Cloud computing, with its dynamic resource pools, virtualization, and high availability, is expected to enable mobile terminal configuration for BIM operation and maintenance platforms in the future, allowing users to directly access required data from cloud platforms via mobile terminals.

(2) **Dynamic real-time interaction between platforms and physical systems.** Existing operation and maintenance platforms primarily function in building and equipment monitoring, representing unidirectional information transmission—essentially "deaf-mute models"that cannot interact with the physical world and lack control applications. How to achieve integrated monitoring and control and dynamic real-time information interaction represents a current research challenge [5][12]. Currently, integrating AR, AV, VR, MR, GIS, and other technologies with BIM has been successfully applied at construction sites, fulfilling the need for real-time interaction between BIM data and actual site environments. Applying AR and other technologies to the operation and maintenance phase can fully realize BIM information value and achieve intuitive, visualized information [37].

(3) **Lack of practical and reliable operation and maintenance management platforms.** Existing operation and maintenance platforms feature single functions, generally targeting only specific functions without forming unified collaborative systems. Most platforms only support building roaming and simple information viewing rather than real-time equipment monitoring. Independent platform development involves high difficulty, long development cycles, and high capital costs, with relatively low application rates [26]. Future platform development will gradually evolve into integrated building collaborative platforms, transitioning from single-domain operation and maintenance to functionally comprehensive operation and maintenance management systems.

(4) **Role positioning issues between BIM-based operation and maintenance platforms and existing systems.** Traditional operation and maintenance management systems (such as BA) are relatively mature and widely applied. However, barriers to new technology adoption persist, lacking positive proof through real cases and return on investment. New technology implementation requires infrastructure investments, such as personnel training and new software tool development, with long ROI cycles. As BIM systems continue to develop and improve, future integration of research with actual engineering projects will serve to verify software functions, cultivate talent, and optimize construction operation and maintenance technologies.

(5) **Conflicts between design and operation and maintenance phases.** Existing BIM clash detection software can only verify physical conflicts in structural layout between operation and maintenance systems and equip-

ment. Problems remain between actual equipment installation and operation during the operation and maintenance phase and clash detection. For example, while clash detection and actual installation may appear problem-free, interference between equipment operation and maintenance information may render certain information inaccessible during the maintenance phase, affecting inspector judgment. Conflicts between design and operation and maintenance phases lead to information mismatches and increased costs. Future operation and maintenance phases will need to better consider human needs and coordination between phases.

(6) **Current BIM technology is only applied to single building management.** With continuous societal development and increasingly complex urban construction, information management models for smart cities have begun attracting attention. City Information Modeling (CIM) [32] represents an extension of urban space—a comprehensive urban application system rather than a simple collection of 2D digital elements and 3D models of urban element systems [25]. CIM faces more complex challenges than isolated building external environment requirements. As a future development direction, BIM technology lays the foundation for integrated urban construction and management.

With the development of intelligent buildings, people have gradually recognized the importance of operation and maintenance management and begun exploring more efficient management methods. As a highly regarded model management approach, BIM can establish not only 3D geometric models but also provide various building component and system information related to buildings. Using BIM as a central repository for building project information has fundamentally transformed traditional building operation and maintenance management. For future BIM technology development in China, emphasis should be placed not only on operation and maintenance platform development but also on improving BIM technology standards, continuously exploring effective application modes, and gradually achieving intelligent operation and maintenance management centered on human needs, human-computer interaction, and information sharing.

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Note: Figure translations are in progress. See original paper for figures.