Research Article

BIM Model Management for BIM-Based Facility Management in Buildings

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Building information modeling (BIM) has recently gained popularity in the architecture, engineering, and construction industry. Specifically, BIM has been applied in facilities management (FM). However, FM-integrated BIM and MM-integrated BIM are likely to fail when BIM-FM models are not effectively updated or maintained. Thus, it is critical to focus on the management of BIM-FM models during the operation stage of buildings. While several researchers have examined BIM applications and system developments in the context of FM, there is a dearth of research on BIM management, particularly in the operation stage of sustainable buildings. Thus, an approach for BIM-FM models management is herein proposed for building projects. A BIM-FM models management (BFMM) system for owners during the operation stage was developed to ensure effective implementation for the management of BIM-FM models. Using a building in Taiwan as a case study, this study discussed and evaluated the effectiveness of the proposed BFMM system. The results reveal that the BFMM system significantly increases the efficiency of BIM-FM model management. The results of this study can provide a useful reference for those interested in adopting BIM to manage building project facilities. This study concludes by presenting the advantages and limitations of BIM-FM models as well as suggestions for future applications.

1. Introduction

Building information modeling (BIM) includes geometry, spatial relationships, geographic information systems, and quantity of various building components. BIM can be applied in determining the life cycle of building or construction projects, including the design stage, construction stage, and operation stage. Particularly, BIM is being widely adopted in various building projects. One of the main features of BIM is 3D illustration, which allows the owners to use BIM for facility management (FM) during the operation stage from design and construction stages [1]. Therefore, management of BIM models for FM (BIM-FM models) is a very important core factor. Although BIM-FM models are available for FM usage during the operation stage, the final implementation result of BIM-FM applications is not successful. When BIM-FM models are incorrect and not properly managed, BIM applications and implementation cannot be executed well and the FM result will have errors [2]. Furthermore, BIM-FM models will lose their credibility among FM engineers. Therefore, suitable management of BIM-FM models will affect the effectiveness of BIM implementation for FM during the project operation stage [3]. The BIM-FM management process includes the development of new BIM-FM models, submission of models for confirmation, modification of BIM-FM models if necessary, and confirmation of modified BIM models prior to delivery to facility owners for use in FM.

A key step in the management of BIM-FM models is updating and modifying BIM-FM models according to process requirements. Failure to properly update and correct BIM-FM models results in the use of outdated or inaccurate versions, leading to unsuccessful implementation of BIM-FM management during the operation stage [4]. Currently, many practical problems have been found to cause unsuccessful FM-based BIM implementation. According to a survey of Taiwanese project owners [5], the existing problems for the practical management of BIM-FM models are...
majorly the following: (1) BIM-FM models are not frequently updated; (2) BIM-FM models do not include the required nongeometrical information for use in FM; (3) there is lack of responsible staff to handle FM-based BIM management tasks in the owner-operator FM organization; (4) there is lack of facility information linked with BIM-FM models; and (5) few suitable platforms exist to assist in the management of BIM-FM models.

Although many previous BIM studies are related to FM, few studies have been conducted on the effective management of the BIM model update mechanism during the operation stage. To improve the owner’s ability to control BIM-FM models more effectively, this study proposes a BIM-FM model for the FM management mechanism and develops a BIM-FM model management platform. Previous literature rarely discussed the BIM-FM models for the FM mechanism. Without suitable BIM-FM models for the FM management mechanism, BIM will encounter many difficulties during the implementation of the use of BIM for FM. At present, there are numerous BIM systems and software developed for FM by researchers and industry. However, few systems are developed which are suitable for the management of the BIM-FM model for FM. To improve the effective implementation of BIM for FM, this study proposes a BIM management approach and develops a system for the management of BIM-FM models for building projects. The main objectives of this study are to (1) propose a management approach for BIM-FM models of building projects, (2) develop a web-based system for the management of BIM-FM models integrated with the proposed approach, (3) apply this system to a case study in Taiwan to confirm the effectiveness of the proposed approach and the system usage by managers of BIM-FM models, and (4) identify the advantages and limitations of applying the proposed management approach and system based on the results of the case study.

The paper begins with literature review. Then, an overview of the proposed method is described, and the development of the prototype system is explained in detail. A case study with an actual building project for FM implementation integrated with BIM is used to verify the prototype system and validate the proposed method. The proposed method and system are compared with traditional FM methods. Then, the results and limitations are discussed and the conclusions are summarized.

2. Background

The construction industry commonly uses BIM from the design to the operation phases of a building’s lifecycle [6]. As a new approach to the design, construction, and management of facilities, BIM promotes the exchange and interoperability of information in digital format during the building process. BIM and its associated processes are being applied to produce and analyze building models [1, 7]. FM departments employ BIM to manage coordinated, consistent, and computable building information [8, 9]. In particular, the approach helps eliminate tedious data entry processes that are prone to errors and information loss during a project’s lifecycle [1, 10]. BIM-integrated FM provides faster data access and helps improve the process of locating various facility elements through its user-friendly 3D interface, thus increasing the efficiency of work order executions [11–16].

Numerous studies have investigated the application of BIM to FM during the operations phase. Becerik-Gerber et al. [17] explored how BIM can be a beneficial platform for supplementing FM practices. Pishdad-Bozorgi et al. [18] proposed a body of knowledge by first defining and examining pilot implementation of FM-enabled BIM and then discussing the challenges encountered. Gao and Pishdad-Bozorgi [15] provided potential solutions for BIM-based FM application challenges and specific recommendations for future research related to BIM-based FM. Kamal et al. [19] proposed an integrated BIM-based framework for effective facility maintenance management.

BIM-based system development has been extensively studied in the past. Some studies have focused on the integration of Industry Foundation Classes (IFC) and BIM for FM [20–24]. Furthermore, numerous studies have focused on BIM integrated with point clouds for FM of existing buildings [16, 25]. Many studies have presented research on BIM-based information system development for FM. Wetzel and Thabet [14] proposed the BIM-based framework to support safe maintenance and repair practices for FM. Suprabhas and Dib [26] developed system integrated sensor data collected using a wireless sensor network via a virtual model of the building. Patacas et al. [27] developed a framework and a prototype system integrated BIM and Common Data Environment (CDE) using open standards for FM. Lavy et al. [28] investigated the effects of using BIM and construction operations building information exchange (COBie) data for FM. Pärna and Edwards [29] presented application programming interface (API) for BIM-FM integration. Pan and Chen [30] developed a BIM-based facility repair platform integrated with QR code for FM. Behlul Kula and Esin Ergen [31] discussed real-life case study implementation of a BIM-FM platform at an international airport project. Mohamed et al. [32] integrated the as-is information BIM and semantic web technology to ensure versatile formalization and management of existing building as-is information. Hsieh et al. [33] proposed a semiautomated FM system to formalize the reuse process of BIM service in semiconductor fabrication plants. Li et al. [34] developed a BIM-enabled BLM system for property owners using a semicustom approach.

Although there are many advantages integrated with various applications of BIM to FM, BIM application in the context of FM can be difficult and even unsuccessful if the BIM-FM models are not accurate or updated [11, 13, 17, 18]. Although previous researchers have focused on different BIM applications and system developments for FM, few have focused on the management of BIM-FM models during the operation stage. Therefore, the present study proposes and develops a system to improve the effectiveness of the management of BIM-FM models in the operation stage of sustainable buildings.
3. Research Method

In this study, all practical problems associated with the management of BIM-FM models are identified and summarized on the basis of the results of interviews. From this, an approach is proposed to solve these practical problems and a system is developed according to the identified requirements. Finally, a case study is applied and discussed to evaluate the effectiveness of the proposed system.

In this study, ten interviews with BIM professionals (with over 12 years’ experience in BIM-FM) were conducted to (1) explore the current state of the practical management of BIM-FM models and (2) identify areas that need further development. The interviews were semi-structured, with the same six open-ended questions asked to each interviewee to capture their understanding of the practical management of BIM-FM models. The six interview questions are as follows:

1. What is your background?
2. What is your role in your BIM-FM project or organization?
3. What are the most important considerations for the successful implementation of the practical management of BIM-FM models?
4. What are the most important requirements for the successful implementation of the practical management of BIM-FM models?
5. What are the most important suggestions for the successful implementation of the practical management of BIM-FM models?
6. What are the helpful system functions that would assist in the implementation of the practical management of BIM-FM models?

The interview results were summarized to identify the important requirements and required system functions to be recognized, and, based on these results, the proposed approach and system development process will be developed. Table 1 summarizes the interview responses.

During the operation stage, when the BIM-FM model needs to be added, updated, or revised, an audit mechanism is required. Although a suitable platform is provided, the implementation of the audit mechanism requires considerable manpower and time, which will lead to considerable difficulties in practical implementation.

It is necessary and essential to provide a correct as-built model or complete inspection of the as-built model for BIM management for BIM-based facility management, without which subsequent revisions and updates of the BIM-FM model will be more labor- and time-intensive. Currently, Taiwan’s large-scale engineering contracts require the delivery and verification of the completed BIM model, which would take 4–6 months (including inspection and correction time). The delivery and verification of the completed BIM model affect the performance of the BIM model management for BIM-based facility management.

At present, many large-scale projects in Taiwan have planned to apply BIM to the entire life cycle, especially in the operation stage. Currently, there are few successful cases of BIM for FM, majorly because of the following problems. First, although the construction general contractor submits the completed BIM model according to contract requirements, the owner does not have a comprehensive plan to effectively convert the completed BIM model into a BIM-FM model. Second, the completed BIM model is directly converted to a BIM-FM model, including the nonessential information present in it. Finally, after maintenance and management, the BIM-FM model is either not updated or updated with no confirmation mechanism.

In general, the model built by the new version of the BIM software cannot be opened by the older version. If the FM department continuously updates the BIM software but there is no high usage during the operation process, then it is an unnecessary expenditure of the limited annual budget allocated for the FM department for BIM management. This eventually results in the FM department not planning to purchase or renew new version of the BIM software. After a few years, the old version of BIM software becomes obsolete for application in BIM model development or modification. Therefore, it is necessary and important to consider software cost for purchasing or renewing new BIM software versions. It is a serious problem in the way of successful implementation of BIM model management for BIM-based facility management.

Currently, there are two different methods for facility owners to handle BIM applications for FM. One method relies on the owner-operator FM organization, while the other relies on FM service providers (BIM outsourcing services) or BIM outsourcing companies. The results of the present study are only suitable for the management of BIM-FM models by owner-operator FM organizations.

This study proposes the principle management components of BIM-FM models, including the development of the new BIM-FM model, submission of the model for confirmation, modification of existing BIM-FM models, submission of the modified model for confirmation, and confirmation of BIM models prior to delivery for application in FM.

Furthermore, all related important information should be recorded and tracked for the management of the BIM-FM models during the modeling process (such as update time, the individual who updated the model, and which content is updated). Finally, the confirmed new or modified BIM models will be delivered to a BIM-based FM system for FM work.

Senior management support is very important for BIM model management for BIM-based facility management. Although BIM has the effect of 3D rendering, the relevant personnel who are already familiar with the FM work have not fully accepted BIM technology. One of the main reasons is that they prefer using the current method without changing the mode for FM work. Therefore, only senior management support and encouragement can effectively implement BIM model management.

FM-based BIM includes the management of geometric and nongeometric information. The requirements for
nongeometric information vary with different BIM-FM models and must be inspected and confirmed prior to model implementation. However, there are a few functionalities designed for the above objects. Therefore, this study aims to enhance the performance of the management of BIM-FM models. Figure 1 illustrates the proposed concept for the management of BIM-FM models.

Based on the FM requirements, there are five major personnel roles for the management of a BIM-FM model: a general contractor, an equipment supplier, an FM engineer, an FM manager, and a BIM engineer. The FM engineer is responsible for submitting applications and requirements to develop a new or modified BIM model for FM during the operation stage. The FM manager handles and manages performance and practical requirements of all BIM-FM models for FM during the operation stage. The BIM engineer develops a new BIM model or modifies existing BIM models for FM based on requirements from FM engineers or FM managers during the operation stage. The general contractor delivers the final as-built BIM model to the owner for FM at the final stage of a construction project. Finally, the equipment supplier delivers the equipment for FM and provides related equipment information for FM during the construction or operation stage.

To enhance the management of BIM-FM models during the modeling process, four statuses for their control and management are proposed: identification, modification, confirmation, and notification. In the identification status, requirements for the development or modification of a BIM model for FM are proposed. In the modification status, a new BIM model is developed or a BIM model is modified for FM based on the requirements. In the confirmation status, the results of the new BIM model development or BIM model modification for FM based on the requirements are confirmed. Finally, in the notification status, notifications are provided to related personnel about the new BIM model development or BIM model modification for FM.

There are two main sources of BIM-FM models: a model from the completed project and a model generated during the operation stage. When a BIM-FM model requires an addition or update, a mechanism needs to be developed for the BIM-FM model management to confirm the BIM-FM model changes and to inspect the results and then notify the relevant stakeholders. With these different statuses, each BIM-FM model can be managed and tracked for effective management. Figure 2 shows the major components of the management of BIM-FM models for owners.

Based on suggestions from the interviews, the five following forms are proposed for assisting in the management of BIM-FM models: a form for the development of new BIM-FM models, a form for the modification of existing BIM-FM models, a form for the confirmation of BIM-FM models, a summary for all process work for the BIM-FM models, and a summary for all confirmed BIM-FM model works. These forms must be integrated with management processes and shared with related personnel. The proposed management framework for BIM-FM models is shown in Figure 3. The four following different flowcharts are presented for enhancing the management mechanisms of BIM-FM models: a main flowchart for the management of BIM-FM models, a flowchart for the development of new BIM-FM models, a flowchart for the modification of existing BIM-FM models, and a flowchart for the confirmation of BIM-FM models.

Figure 4 shows the flowchart explaining the major workflow for system development for the management of BIM-FM models. The flowchart includes the four main stages in the management of BIM-FM models, namely,
identification, modification, confirmation, and notification statuses. This management process involves new model development, correct confirmation for the final model, and notifying relevant personnel regarding the confirmation. Each stage includes decisions for controlling and managing BIM-FM models. The entire management and control of the workflow are executed through the proposed system, with the BIM-FM models following the management mechanism integrated with relevant personnel and other important information.

4. System Development

To achieve the proposed management mechanism, a BIM-FM model management (BFMM) system is designed and developed based on the identified requirements for the management of BIM-FM models. Furthermore, the major purposes of the BFMM system are to (1) provide an overview of the current state of all BIM-FM models, (2) provide the required checklist of nongeometric information for the BIM-FM model, and (3) show the version history and record changes of the BIM-FM models.

Windows 10 is selected as the operating system for the proposed BFMM system, programmed using the Navisworks API. The portal subsystem of the BFMM system is programmed using Java Server Pages (JSP). All authorized users can access the portal subsystem of the BFMM system through web browsers. The BFMM system comprises interface, access, application, and database layers. The interface layer executes administrative work at the end-user side. The access layer carries out system administration and security. The application layer provides the major functions of the system based on client requests. Finally, the database layer organizes and stores data and information during the system processes. The framework and related modules of the BFMM system are illustrated in Figure 5.

Four modules are designed and developed in the BFMM system. The major functions of the modules are to handle versioning, status selection, result updating, statistic collection, and workflow control for BIM-FM management. This following section will explain the function of each module of the BFMM system.

4.1. BIM-FM Model Editing Module. This module allows users to edit the required content for the development of new BIM-FM models or for modifying existing BIM-FM models. After submission of the BIM-FM model, the required nongeometric information of the BIM-FM model will be inspected. This module lets the FM engineer edit the required description and submit the BIM-FM model. After the request is approved by
the BIM manager or the FM manager, the process will be recorded and tracked. Furthermore, the module will include the relevant important information (such as 2D location details and related supplemental and requested photos from the BIM-FM models for FM).

4.2. **Historical Record Module.** This module provides a collection of historical records of all submitted BIM-FM models. In general, it is necessary and important for reference to record previous versions of BIM-FM models. These historical records include the responsible BIM engineer’s name, the previous modified version of the BIM-FM model, and previously recorded brief explanations of modifications of the BIM-FM model. This module enhances the complete version history for different versions of BIM-FM models.

4.3. **Dashboard Module.** This module can display the current result of the BIM-FM models as shown via a dashboard. The major advantage of this module is that a simple bar and pie chart is presented for use in major control management of the BIM-FM models. It is necessary and important for managers to access the current management condition of BIM-FM models through the module.

4.4. **Analysis Module.** This module can show the analysis and statistical result of BIM-FM models displayed by the dashboard. The major functionality of this module is to illustrate model statistics for management of available BIM-FM models in the project. It is helpful for the relevant personnel to understand the current statistics related to the management of BIM-FM models for advanced decision-making.

Furthermore, the following Revit API and Navisworks API subsystems were developed to enhance efficiency.

4.5. **API Module for Explanation of Modifications.** This module allows users to edit the brief summaries used for explaining modifications made to the BIM-FM model. Furthermore, the system automatically exports the brief summary to update the historical summaries of the modifications made for the selected modified BIM-FM model.

4.6. **API Module for Information of the Modified BIM Model.** This module allows users to store angle and distance information to explain BIM model modifications clearly and easily. This function can effectively illustrate the modified BIM model.
4.7. API Module for 2D Location with Errors. This module lets users edit 2D locations for required modification of errors or problematic locations. To enhance the effective modification of BIM models, this module allows users to mark the 2D map to show the modified location in the BIM model.

4.8. API Module for Automatic Model Transfer. This module helps users transfer and update new or modified BIM-FM models to the FM system without manual operation. In addition, the module will record and summarize details for the BIM-FM models transfer to the FM system.

5. Pilot Case Study

5.1. Case Study Implementation. To determine the advantages and limitations of the proposed approach and BFMM system, they were applied to a new office building in Taipei, Taiwan. This building mainly provides office space (a total floor area of approximately 18054 m²) and includes 14 floors above ground and a four-story underground parking garage. BIM was implemented during the design and construction stages as the owner planned originally to use BIM to assist in FM implementation. Before the project was completed, the general contractor delivered completed as-built BIM models for the owner according to the contract. During the construction phase, all the as-built BIM models were developed and updated by general contractors and subcontractors based on all requirements of contacts. Finally, the general contractors updated and combined all the as-built BIM models for completed as-built BIM models at the closeout of the project. The completed as-built BIM models include completed as-built BIM models for architecture, structure, and mechanical, electrical, and plumbing (MEP). Furthermore, the general contractors were required to enter the nongeometric information of important completed as-built BIM models for equipment and facilities (such as information for equipment supply name and purchase time).

After the completed as-built BIM models were developed by the general contractor, they were handed over to the owner, inspected, and confirmed. The completed as-built BIM models received by the owner were continued to be updated with BIM-FM models added as necessary for FM, with the owner assigning one full-time BIM engineer and one junior FM engineer as a BIM part-time engineer responsible for the maintenance of BIM-FM models. The duration of the pilot study was fifteen months and the major participants included BIM engineers, FM engineers, FM manager, and suppliers (general contractors and equipment suppliers).
At the closeout of the building construction project, engineers under the general contractor were asked to prepare and submit the completed as-built BIM to the BFMM system. During the closeout stage, the engineers inspected the completed as-built BIM based on the contract requirements. Identified problems and suggestions to correct the BIM were communicated and responded to through the BFMM system, with related records and submitted documents collected and stored in the system. The general contractor then corrected and modified the model according to the comments. Once all issues were rectified, the completed as-built BIM was stored as the FM-based BIM. In the case study, the first edition of BIM-FM models was developed and submitted by general contractors at the completion of the case study. In the beginning of the operation phase, the BIM-FM models were updated as the second edition for the usage of interior decoration. After 10 months, a new department was added and moved in the building, and the interior design was modified again based on the new requirement. Therefore, the second edition of BIM-FM models was developed and submitted by general contractors at the completion of the case study. In the beginning of the operation phase, the BIM-FM models were updated as the second edition for the usage of interior decoration. After 10 months, a new department was added and moved in the building, and the interior design was modified again based on the new requirement. Therefore, the second edition of BIM-FM models was developed and submitted by general contractors at the completion of the case study. In the beginning of the operation phase, the BIM-FM models were updated as the second edition for the usage of interior decoration. After 10 months, a new department was added and moved in the building, and the interior design was modified again based on the new requirement. 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5.2. Discussion. After the pilot case study, the system was verified to evaluate the system usage. All related participants were required to answer the questionnaire and provide feedback. The participants included two FM managers, ten FM engineers, two BIM engineers, two engineers of general contractor, and three suppliers. Table 2 illustrates the results of the system usage evaluation. Table 3 summarizes the comments from the system evaluation.

The following are the key questionnaire results that highlight the major benefits of the BFMM system. First, 92% of the respondents stated that the system effectively records all historical information on the FM-based BIM. Second, 89% agreed that it displayed all recent results and statuses for newly developed or modified FM-based BIM models during the project. Finally, 90% agreed that the system confirms the correctness of the new or modified FM-based BIM models.

Figure 8 demonstrates the percentage for the major problems of BIM-FM models based on the case study. There are 176 total different problems encountered in the case study. As shown in the figure, most respondents reported existing problems related to no updated BIM-FM models (28%), no BIM-FM model developments for new facilities (28%), and having insufficient time for new developments or
upsetting (20%). Fewer respondents reported problems related to incorrect BIM-FM model developments (14%) and lack of expertise for BIM-FM works (10%).

Figure 9 displays the difficulties in the implementation of the BIM-FM model management in the case study. There are 123 total different difficulties encountered in the case study. As shown in the figure, the majority of respondents reported difficulty in providing sufficient incentive for implementation (22%), having insufficient manpower for implementation (20%), having inadequate responses for clients (18%), having insufficient time to develop new models for new facilities (16%), and having insufficient time to update and modify the models (15%). By contrast, few respondents reported difficulties in problems for lack of BIM-related expertise for implementation (9%).

We identified the following limitations and barriers for the proposed BFMM system:

(1) No BIM engineer was hired in this project. Therefore, the management of the BIM-FM models was done by one of the full-time FM engineers. Although this FM engineer has the BIM skills to handle the modification of the BIM model, they lacked the time to perform these modifications. Without full-time BIM engineers to handle BIM-FM models, a situation can arise where there are no persons to perform the maintenance management of the BIM-FM models. Most FM engineers are occupied with their primary responsibilities and are not available for part-time tasks for the modification of BIM-FM models.

(2) Based on the case study results, another problem is the entry of nongeometric information in the BIM model. There are serious problems regarding missing nongeometric information in the BIM models, which, in the case study, include information about the model of the equipment, information about the purchase time of the equipment, information about the maintenance of the facility, and basis required information about regular maintenance of important equipment or facilities (such as elevators). The missing nongeometric information in the case study can be explained by three important reasons. First, most of the paper-based handover documents for equipment and facilities submitted by suppliers do not include the required nongeometric information. Second, it is ineffective for general contractors to enter the nongeometric information for completed as-built BIM models from paper-based handover documents at the closeout of the project. Third, engineers for the general contractors and equipment suppliers may not have sufficient time to enter the nongeometric information of a BIM model, depending on the contract requirements.

(3) In the case study for FM engineers and FM managers or owners, it is still challenging to inspect the completed as-built BIM model provided by the general contractor. The requirements for the
completed as-built BIM model will vary depending on the contract, and the contents and results are manually inspected and confirmed. Therefore, a large amount of time and effort is still needed to check the BIM-FM models.

(4) It is strongly suggested that the BIM-FM models for an equipment should be developed by the equipment suppliers. Facility suppliers will easily and effectively understand the relevant important information for the BIM-FM models of the equipment. Furthermore, they will understand variances between the different types of equipment. Therefore, it is suggested that equipment suppliers should provide the BIM models for facilities with related important information when they sell facilities.

(5) In this case study, the owner assigned the owner-operator the responsibility of handling the BIM for FM. The proposed management mechanism and flowcharts will differ if owners handle the management of BIM-FM models through FM service providers (BIM outsourcing services).

(6) In the maintenance and management stage, the maintenance personnel of the maintenance management BIM model and the maintenance management-related personnel are not necessarily the same group. When the maintenance management-related personnel complete the maintenance work, how to notify the maintenance management BIM model for FM use? The system can help us to collect, trace, and manage all submissions of updated BIM models. The system is different from other current software.

(7) In the operation stage, most FM departments will not hire a full-time BIM engineer. The major reason is that the operation stage will require considerable BIM verification and correction operations at the beginning, and the usual workload is not very high after entering normal operation. Therefore, it is recommended that the FM department can train a

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**Table 2: The result of system usage evaluation.**

| Title description                                      | Mean score |
|--------------------------------------------------------|------------|
| Applies suitable BIM use for FM                        | 4.24       |
| Ease of use                                            | 4.12       |
| Clear user interface                                   | 4.32       |
| Reduces rework time                                    | 4.18       |
| Effectively tracks modification results of BIM-FM models| 4.52       |
| Effectively accesses historical record of modifying BIM-FM models| 4.43       |
| Enhances correction management of BIM-FM models modification| 4.72       |
| Improves workflow management of BIM-FM models modification | 4.38       |
| Improves data reentry problems for BIM-FM models       | 4.16       |

*Note. The score for mean is calculated based on respondents’ feedback using a questionnaire with a scale of 1–5 (1 indicates strongly disagree and 5 indicates strongly agree).*

**Table 3: System evaluation comments.**

| No. | Participant comments |
|-----|----------------------|
| 1   | FM engineer: It is very convenient for me to access the latest BIM model for FM. I used to utilize the cloud-based database to store the BIM model. However, the solution is not efficient for me for maintenance management of facility BIM models for FM use. |
| 2   | FM engineer: It is effective for storing all updated BIM models for FM use when a BIM model is updated or a new BIM model is developed for a new facility using the proposed system. The proposed system provides an effective platform for sharing the latest FM BIM model for FM use. |
| 3   | FM manager: It is very important for me to inspect all available BIM models for FM for the building. I may refer to all previous updated BIM models to compare the differences through the system. All ongoing or delayed work for maintenance management of facility BIM models can be managed and tracked effectively by the system. |
| 4   | Owner: Regarding the application of BIM for FM, it is very important to keep the BIM model for the latest status. Therefore, it is necessary to provide a platform for the management of BIM models of facilities. Although there are many commercial software programs designed and developed for various BIM applications, there are few systems developed specially for the management of maintenance of BIM models of facilities. |
| 5   | BIM engineer: I think that the system is necessary for the application of BIM for FM. Especially for changes to the space or decorations of a building, the modification of BIM models can be executed and confirmed before the use of FM. The system can help us to collect, trace, and manage all submissions of updated BIM models. The system is different from other current software. |
| 6   | Equipment supplier: It is a great idea for us to submit the BIM model for newly purchased equipment through the system directly. After submitting the BIM model of the new equipment, the system will illustrate the summary information and automatically check if the required information of BIM model meets the requirements. |
| 7   | FM manager: By using the proposed BFMM system, it is very convenient for me to access and understand the current state for BIM-FM models management. Without the use of BFMM, it is difficult for managers to handle and manage all BIM-FM models for different buildings. |
part-time FM engineer or outsource the BIM-FM model for import. If the part-time FM engineer of the internal FM department is used, it is necessary to consider that the FM engineer cannot change the work content frequently. Otherwise, there will be no time for the FM engineer to handle BIM development and corrections if the FM engineer is too busy.

We summarize the following major suggestions based on the case study:

(1) For new equipment, the owner needs to develop a new BIM model if the equipment supplier does not provide a BIM model. It will take significant time and effort for FM engineers to develop a BIM model for the new equipment by themselves.

(2) It is necessary to set up the management mechanisms for BIM-FM models in advance. The management mechanism for BIM-FM models includes the initial plan, personnel involved, and control flowcharts for management of BIM-FM models. These management mechanisms will be identified and planned based on the requirements and organization for FM.

(3) When the maintenance work is outsourced, it is necessary to notify the maintenance and management BIM model maintainers of the updated content after the maintenance work is completed by the outsourced maintenance management personnel. In the past, it was difficult for the maintenance and management BIM model maintainers experienced in Taiwan to request the commission. External maintenance and management personnel provide sufficient information; hence, maintenance BIM model maintainers will face problems such as not knowing when to update and what to update.

(4) It is important to identify the requirements for BIM-FM models in advance. There are no BIM-FM models for select facilities, as the owner does not plan to use BIM for FM for these facilities (such as lights in the case study). Therefore, new BIM-FM models for these facilities were not required when the facilities were purchased during the operation stage. The owner needs to identify which BIM-FM models need to be developed for use in FM in advance; otherwise, time and labor will be required to develop unnecessary BIM-FM models.

6. Conclusions

In recent years, BIM has been regarded as one of the main visual tools for FM applications. When BIM technology is integrated with FM solutions, it is necessary and important to consider the effective management of BIM-FM models for the successful implementation of the integration of BIM and FM. Successful BIM-FM implementation is challenging.
without the effective management of BIM-FM models. Many previous research efforts and case studies have focused on FM-related applications and system development in academic and industrial fields. However, few studies have focused on BIM-FM management during the operation stage of a project. Furthermore, there are many commercial software programs developed for BIM application for FM, and the main purpose of these programs is to provide FM-related applications instead of BIM-FM management. This is the main contribution of this study, as compared to previous research and studies.

The objectives of this study were to (1) propose a management approach for BIM-FM models of building projects, (2) develop a management system for BIM-FM models based on the proposed approach, (3) apply this system to a case study in Taiwan to confirm the effectiveness of the proposed approach and system usage specifically for the management of BIM-FM models, and (4) identify the major advantages and limitations of the proposed approach and system.

The major suggestions derived from this study are as follows: (1) BIM-FM models should be updated frequently to confirm the accuracy of the BIM-FM models; (2) the FM department should carefully plan and set up the management mechanisms for BIM-FM models based on requirements; (3) top management should support the management of BIM-FM models if the owner plans to utilize BIM technology for FM; (4) owners should rely on their owner-operator FM organization to handle BIM application for FM; and (5) facility suppliers should provide the BIM models for facilities with the relevant important information when they sell facilities.

Owing to the different types and attributes of FM organizations, the roles and management processes mentioned in this study will vary; nevertheless, the proposed core concepts and methods in this study remain relevant. These roles and processes can be adjusted and modified based on FM organization types and attributes to meet the requirements and purposes of management of BIM models for FM in the FM organization.

Further steps are required to continue to develop and link the BFMM system and the BIM-based FM systems. With assistance provided by the BFMM system for the owner, updated BIM models can be collected and managed effectively during the operation stage. Furthermore, the updated BIM models delivered by the BFMM system can enhance the successful implementation of BIM-based FM systems.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

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

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