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Research Article

Engagement of Facilities Management in Design Stage through BIM: Framework and a Case Study

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Considering facilities management (FM) at the early design stage could potentially reduce the efforts for maintenance during the operational phase of facilities. Few efforts in construction industry have involved facility managers into the design phase. It was suggested that early adoption of facilities management will contribute to reducing the needs for major repairs and alternations that will otherwise occur at the operational phase. There should be an integrated data source providing information support for the building lifecycle. It is envisaged that Building Information Modelling (BIM) would fill the gap by acting as a visual model and a database throughout the building lifecycle. This paper develops a framework of how FM can be considered in design stage through BIM. Based on the framework, the paper explores how BIM will beneficially support FM in the design phase, such as space planning and energy analysis. A case study of using BIM to design facility managers' travelling path in the maintenance process is presented. The results show that early adoption of FM in design stage with BIM can significantly reduce life cycle costs.

1. Introduction

According to the International Facility Management Association (IFMA), facility management (FM) is defined as "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, processes and technology" [1]. Industries in varieties of areas are adopting BIM for FM. Organizations such university, government, healthcare, retail, and information technology are taking a survey for the adoption of BIM-based FM [2]. Different parts of FM are adopted with BIM in these organizations. Figure 1 depicts the proportion of each function.

However, few efforts in the construction industry have involved facility FM into the design phase [3, 4]. It was suggested that early engagement of FM would contribute to reducing the needs for major repairs and alternations that will otherwise occur at the operational phase [2, 5]. There have been rare effective approaches or processes to engage FM in design stage. The proposed framework of this paper is going to integrate these FM works into early design stage which could potentially strengthen the collaboration between design team and FM team and reduce alternations. BIM is envisaged to be an effective tool, as proposed in this paper. Considering the multidisciplinary and interoperability of this process, there must be a data source providing convenient integration and access to the relevant information. Building Information Modelling (BIM) is a conceptual approach to building design and construction that comprises all the graphic and linguistic data of building for design and detailing which facilitates exchange of building information between design, construction, and operational phase [6]. A BIM model could comprise individual 3D models of each building component with all associated properties such as weight, material, length, height, geographical information system GIS and information [7]. Beyond the inherent information, BIM also includes external association between building components. For example, the column with name Col. −093 is installed between box ceiling Cei. −52 and level 2 floor with GUID number 30836. Figure 2 depicts the column model and associated properties. The main difference

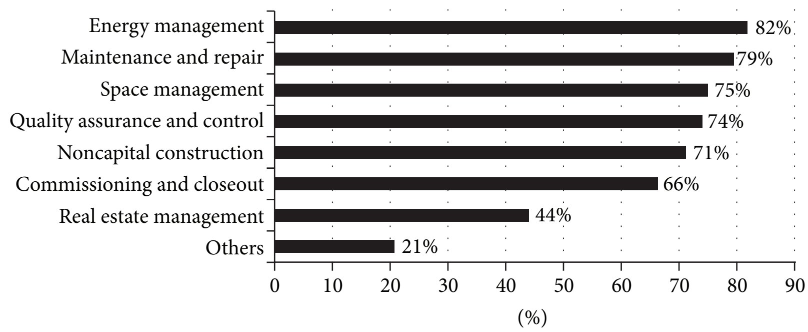

Figure 1: Proportion of each function [2].

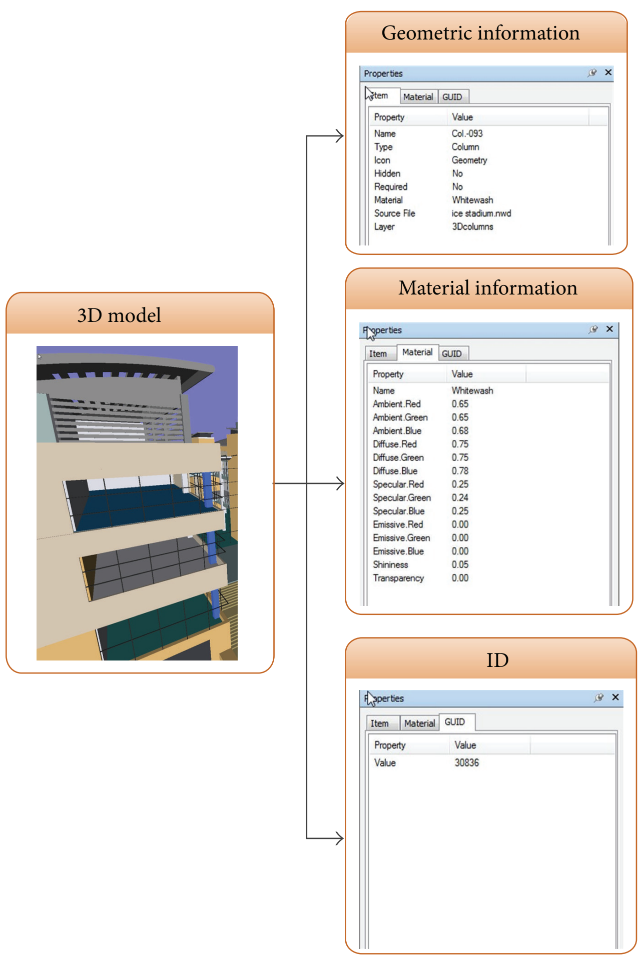

Figure 2: Column model and properties in BIM.

between BIM and 2D CAD is that the latter describes a building layer by layer [8]. Editing one layer will result in massive updating and checking work of associated floor plan. In contrast, BIM models are designed in terms of building components in 3D view. An error-prone process such as clash detection could be conducted automatically [9]. This paper aims to develop a framework of bringing facility management into design stage through BIM. Which field of FM work should be brought to the design stage and which data should be collected are also proposed. With the ease of access to lifecycle information of all the building components BIM provided, proposed building plan could be optimized and lifecycle cost could be reduced with the FM knowledge and experience.

2. Methodology: Conceptual Framework of Integrating FM and BIM in Design Stage

Erdener [5] developed a framework linking design with FM by programming—an extension of "problem defining-solving method" which however did not classify the specific field of work in FM that should be involved into the design stage. Additionally, the backend database was not adopted as an approach to integrate the massive information such as asset portfolios, instructions, and design manuals in this multidisciplinary process. Mostly, the operation and maintenance process of a facility occupies more than 80% in its lifecycle for both cost and time [10]. During the FM process, facility managers have to acquire, integrate, edit, and update massive information related to diverse building elements such as operational costs, warranties, and specifications from varieties of systems. BIM could effectively merge these primary data and provide convenient storage and retrieval of these FM data. Based on the work of Becerik-Gerber et al. [2], three types of FM data should be incorporated into BIM: (1) equipment and systems, (2) attributes and data, (3) portfolios and documents. Figure 3 illustrates the structure of the proposed BIM database for FM. Every facility in buildings is regarded as an individual entity with two kinds of properties—attributes and portfolios. Six types of basic equipment such as HVAC, plumbing, and electrical are represented as entities in BIM. Each entity has its attributes (vender information, location information, etc.) and attached documents (specifications, warranties, manuals, etc.). Specifically, serial numbers of products specified by vendors will be collected as unique identifier for each facility. Model and part numbers will act as reference information during the maintenance. Location information is comprised of building number, floor, and room number. Description stores the status of the facility. Attributes include weight, power, and energy consumption. In order to integrate the whole information into one standardised BIM database, interoperability needs to be assured. This is partially because in different circumstances different

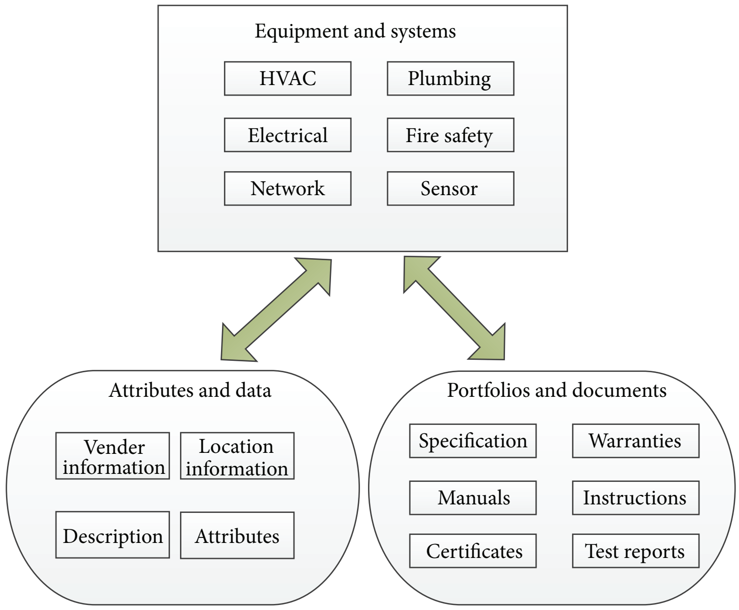

FIGURE 3: FM based BIM database.

FM software systems are adopted, that is, *Mainpac* for building maintenance; *FaPI* for monitoring building condition; *TRIM* for document management. Nevertheless, all these software have their own data structure and usually they are not compatible with each other. International Alliance for Interoperability (IAI) published the Industry Foundation Classes (IFC), a standard for BIM data structure based on an ISO standard (ISO, 1994) enabling exchange of information among heterogeneous systems [11].

BIM will provide supporting information for many categories of FM work such as maintenance and repair, energy management, commissioning, safety, and space management. Three categories of FM during the building's lifecycle are determined to be the most proper and specially discussed in this paper—(1) maintenance and repair, (2) energy management, and (3) commissioning. The decisions made in the design stage affect all aspects in maintenance stage and vice versa. The designer's relationship with the other participants in maintenance stages is very important [12]. Therefore, the maintenance team should also be involved into design stage for decision making. Additionally, different energy saving alternatives can be explored and simulated in early design stage with BIM [13]. Last but not least, commissioning stage ensures that a new building or system begins its life cycle at optimal productivity [14], in which coordination and information sharing between designer and participants essential.

This transformation will provide evaluation information for the design team and make the decision making much easier in both strategic-tactical and operational phase.

For the former, the facility manager could provide post occupancy evaluation of facilities for the design team as feedback. For the latter, bringing these FM jobs into the design stage will avoid redesign and reduce the maintenance job. The following subsection discusses the BIM role in FM engagement in design stage in detail.

2.1. Maintenance and Repair. Maintenance is defined as activities required keeping a facility in as-built condition, while continuing to maintain its original productivity [12]. During this procedure, FM personnel have to identify the components' location and get access to the relevant documents, and finally, the maintenance information. In the state-of-the-art design phase, facility management relevant information such as working space of equipment, storage condition, and weight are not considered. This directly leads to the inappropriate allocation of space and incorrect estimation of load expectations.

Location information of facility could help facility managers efficiently identify the location of specific building components, especially for those who outsource the FM tasks. The knowledge and experience of facility managers could inform the architecture designers with working condition and space of different facilities. Both interior and exterior space requirements must be considered for the normal installation and implementation. Interior space refers to the working space, storage space, and privacy of the space. Exterior space includes the spaces needed for installation and, in case of emergency, for people's escape route. All the above issues could be incorporated into BIM and shown in graphical interface for the discussion between designers and facility managers.

Additionally, FM personnel could retrieve the relevant data of task from BIM's graphical interface in real time. For example, when troubleshooting a printer, FM personnel have to check the maintenance history, get the maintenance manual, generate maintenance reports, and close the request. Conventionally, they have to log on to different electronic document management systems (EDMSs) and toggle between multiple databases to retrieve relevant information.

Preventative maintenance (PM) is defined as the care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects [15]. For the matter of regular inspections, a schedule will be prepared. Detailed work description is preferred for improving the overall productivity that is work order ID, facility ID, location, description of the preventive work, documents required to perform maintenance, estimated and actual labour hours, and frequency of maintenance work [12]. All these data could be incorporated into BIM database as attributes and documents. Considering the unique ID of every facility, each one could be assigned an associated barcode for the ease of access to relevant information in real time through mobile device. Additionally, after every time of maintenance, status information and working hours will be sent to BIM as feedback and reference for next turn. Figure 4 depicts the workflow of BIM-based PM. Through predesigning of maintenance information such as location information, relevant maintenance history, and schedule for PM with BIM, incorporated information could be accessed conveniently. Future maintenance will be reasonable, and redesign is avoided.

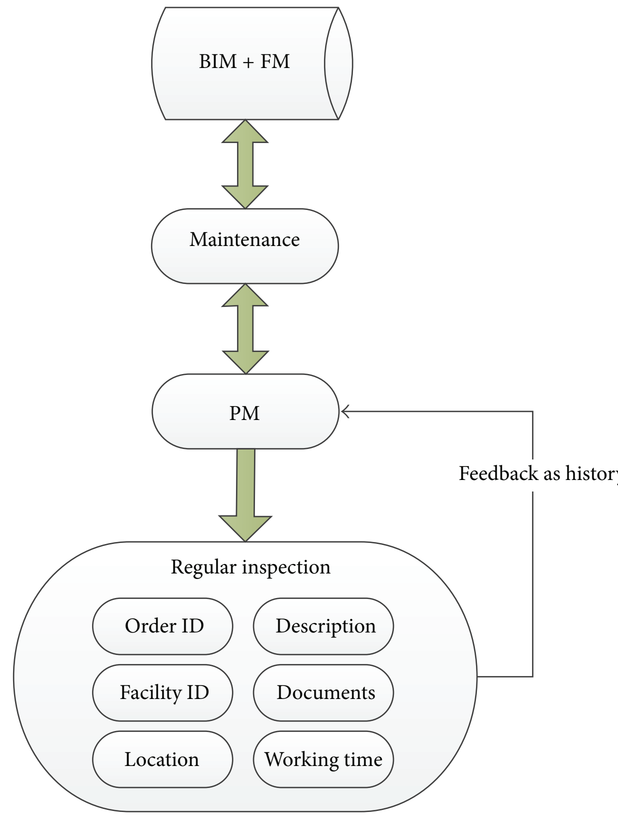

Figure 4: BIM-based PM workflow.

2.2. Energy Management. Statistics from the US Green Building Council [16] show that in the United States, 72% of electricity consumption, 39% of energy use, and 38% of all carbon dioxide are from buildings. However, most buildings are not optimized in terms of energy consumption or not professionally optimized with advice or knowledge of facility management teams [13]. Torcellini et al. [17] identified "designing and constructing low-energy buildings (buildings that consume 50% to 70% less energy than code-compliant buildings) require the design team to follow an energy-design process that considers how the building envelope and systems work together." Energy consumption design must be set by the design team in the predesign phase. Afterwards, virtual prototyping will be created to simulate the energy efficiency. Acquainted with knowledge on energy codes and standards, the building energy consultant in FM team can provide all the information related to energy consumption for the basic energy analyses [17]. However, traditionally, most building energy analyses have been conducted late in design. Due to the difficulty and expense of modelling the energy systems, identifying and validating energy saving alternatives with different models is not economically possible. A large portion of time will be consumed in converting floor plans to energy management system graphics [4]. BIM is envisaged to be the platform for data exchanging avoiding reentering all the building geometry, enclosure, and HVAC information. Interoperability can be overcome by the data exchange standard gbXML (Green Building Extensible Markup). BIM software such as *Bentley*, *Autodesk Revit*, *Graphisoft ArchiCAD*, and *Google sketchUp* are able to export energy analyses data in gbXML format. For overall BIM energy design of a building, three steps have to be executed based on Kim et al.'s [13] work as follows.

(1) Create BIM Model of Building. BIM model could be created based on the existing floor plan. This model comprises structured building components which include spatial data, texts, and databases of other properties. Based on these data, volume can be calculated, as well as energy estimates.

(2) Integrate Energy Consumption Data and Test to Identify an Alternative. After modelling, energy consumption relevant data could be exported in gbXML format and analysed by tools such as *Ecotect*, *Green Building Studio*, and *DOE-2.* gbXML data could be used to analyse the energy consumption of the whole building, estimate water usage and cost evaluation, visualize solar radiation on surfaces, and simulate daylight factors [18]. Alternative design could be simulated by changing the lighting, roof, and walls.

(3) Validation of the Proposed Design. After a design alternative is specified, validation from energy consultant is essential. Logic and assumptions of the energy model must be carefully reviewed. Figure 5 depicts the framework of energy management design using BIM.

Treating each energy-consuming object as an entity, real time and period energy consumption will be collected as one of its property. Thus, cost information of a room/zone could be calculated by adding up all the energy cost of energy-consuming objects in it. Some high-energy-consumption facilities' information could be predicted by the historical data.

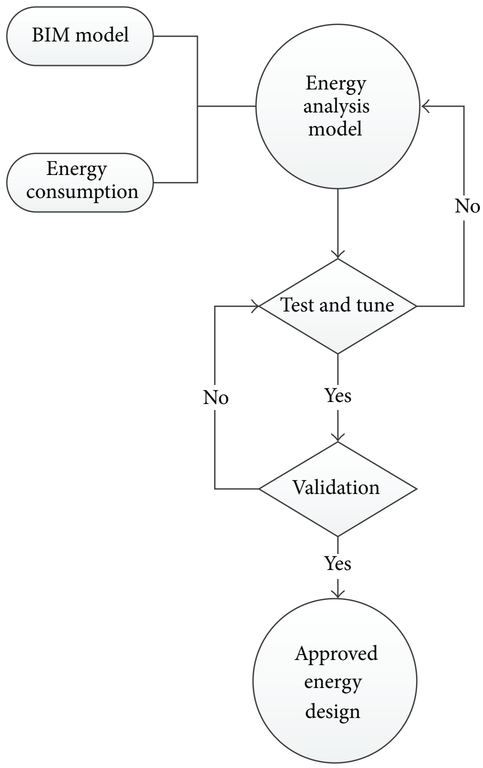

Figure 5: Framework of energy management design using BIM.

2.3. Commissioning and Handover. Building commissioning is defined as "a quality assurance program intended to demonstrate that the building is constructed well and performs as designed. If the building materials, equipment and systems were not installed well and are not operating as intended, the health, productivity and other benefits of high performance design will not be achieved" [19]. Building commissioning is a key process for the building operation and maintenance, as the Department of Energy (DOE) suggested that "it ensures that a new building or system begins its life cycle at optimal productivity and improves the likelihood that the equipment will maintain this level of performance throughout its life. Building commissioning is the key to quality assurance in more than one way" [20]. For evaluating the project quality and identify potential significant design defects before it is too late or expensive to make changes, building commissioning should be embedded in the following phases: predesign phase, design phase, construction phase, transition to operational sustainability, postoccupancy and warranty phase, and retrocommissioning [21]. This section is focused on the first two processes: predesign phase and design phase. In design stages, commissioning scope and commissioning team must be identified. Since different facilities have different features and budget limitations and different projects have special systems to be commissioned, commissioning team has to be involved in early design stages for the decision making. This approach will also enable knowledge sharing between different parties. However, in the process of commissioning, massive 2D documents, images, maintenance, and operation information need to be collected and accessed frequently. For example, in the commissioning process of the Maryland General Hospital (MGH), the following systems need to be commissioned: a new 2000KVA normal power substation, a new 500 KW emergency generator and paralleling switchgear, three new automatic transfer switches and distributions, 2 new 650 ton electric centrifugal chillers and 650 ton cooling towers, temperature and humidity systems, and duct work, air handlers, dampers, and fans [21]. There has to be an easily accessed platform for data exchange and integration. BIM is envisaged to overcome the problem of interoperability and provide easy access for these massive data. When scoping which facilities need to be commissioned, similar projects' information could be retrieved from BIM database, as reference for the decision. The graphical interface of BIM could also improve the collaboration among owner, designer, and contractor. Schedules and commission facilities could be predesigned and stored in BIM models by each facility/zone/room. These plans are shown as timeline, which act as a simulation of actual commissioning practice. Thus, the logical faults and collision between activities can be easily identified. Moreover, design errors and conflicts of plumbing, HVAC, and electrical from different team could be discovered in the integrated view of BIM. In the design phase, different commissioning tasks have to be assigned to the specified experts for individual commissioning. After all these commissioning subtasks are approved, the whole system has to be commissioned together. For example, plumbing and electrical systems in a room need to be commissioned in a designed order. After both are approved, it must be ensured, these systems could work together successfully. Thus, the overall commissioning task must be done. When commissioning the plumbing or electrical system in different areas, a logical order must be specified. Simulating this schedule and identifying an optimal alternative will reduce the commissioning cost and time. Figure 6 depicts the BIM-based commissioning streamline.

Barcode system could also be incorporated into BIM for the ease of accessibility of commissioning documents. Each commissioning facility is assigned a unique ID in the BIM model for storing the properties and relevant documents when it is designed. Each ID could be associated with one barcode. The commissioning team could scan the barcode and retrieve the product data, operation data, and maintenance manuals right in the field. Commissioning critical tasks and checklists could be pushed on to a mobile device. The results will be automatically uploaded to BIM central database in a standard format after commissioning tasks.

As project proceeds, these data are handed over to the operational phase as well as the updated BIM model. Besides correcting design defects, simulating commissioning schedules, and bringing easy access for information, bringing commissioning to design phase through BIM could also improve energy saving performance in operation and maintenance phase.

3. Case Study

The project of Shanghai Disaster Tolerance Center is an ideal example of bringing FM to design stages through BIM.

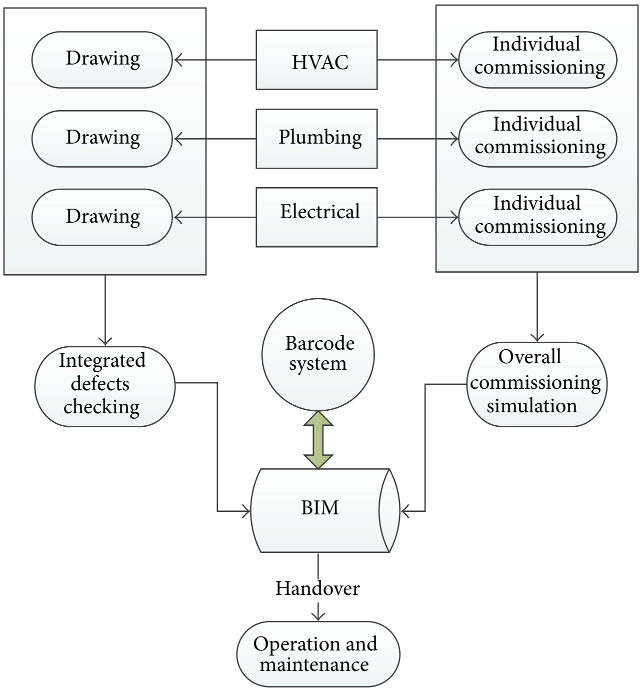

Figure 6: BIM-based commissioning streamline.

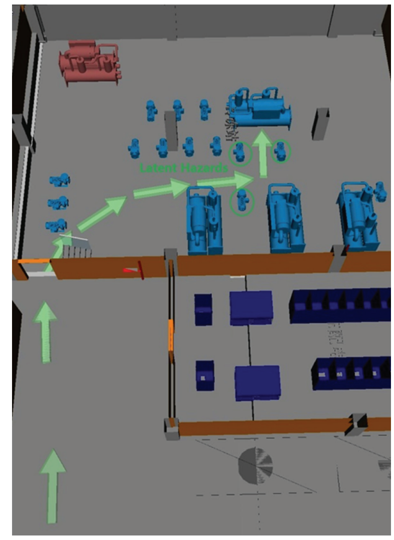

Figure 7: Traditional travelling path and latent hazards.

Travelling path of facility manager is predesigned in BIM thus reducing the maintenance time and providing easy access to the location information of facilities.

3.1. Project Overview. Shanghai Disaster Tolerance Center is in the north of the North Industrial Park in Shanghai, China. It was designed in September of 2010 as a State Grid Corporation of centralized information systems data center. The construction area is 28,124 square meters with one underground layer and four floors on the ground. The diesel generator room and pump are 9.1 meters in height, with construction area of 1,703 square meters. Shanghai Municipal Electric Power Company is the construction company. Shanghai Modern Architectural Design Co., Ltd. is the design company. This project is complicated in facility systems with a tight schedule. High-standard requirements of materials and labor cost control are other characteristics of this project. BIM has been decided to be the tool to bring the FM work into design stage for predesign and simulating the maintenance work in FM.

3.2. BIM Services Content. Accurate BIM model of the mechanical, electrical, construction, and interior decoration are created based on 2D drawings provided by the owner. Clash detection of pipelines is conducted and optimized. BIM model is used for scheduling and guiding the on-site construction work. A 4D construction simulation is also conducted based on the BIM model. Security control and quantity takeoff are based on analysis of pedestrian stream. Construction schedule needs to be incorporated into model in order to visualize the construction process in BIM model. Last but not least, a database platform is developed to read BA surveillance data and conduct real time positioning in 3D mode to get location of facilities thus facilitating maintenance work. This improves the monitoring ability and security level of the disaster tolerance center.

3.3. BIM-Based Travelling Path Optimization in Maintenance. During the process of maintenance, FM personnel have to identify the components' location, getting access to the relevant documents, and finally, the maintenance information. Location information of facility could help facility managers efficiently identify the location of specific building components, especially for those who outsource the FM tasks. Conventionally, they have to log on to different electronic document management systems (EDMSs) and toggle between multiple databases to get the location information, relevant maintenance manuals, and warranty documents. BIM could integrate all these information together in a graphical view. By predesigning the travelling path in the maintenance job, travelling time is well scheduled and reduced and latent hazards could be avoided. Traditionally, after identifying the building number and room number, FM personnel just go to the maintenance spot through a normal path, which may be not the shortest path. Moreover, latent hazards are not identified because of lack in relevant knowledge. Figure 7 depicts the normal travelling path and latent hazards. Since there are different kinds of latent hazards in different areas, the travelling path needs to be identified with the knowledge of all departments of FM teams. After discussion between spatial experts and FM team, an optimal path is specified and incorporated into BIM database, which is safe and consumes the littlest time.

In the following scenario, using BIM to design, optimize, and simulate the path of troubleshooting, the reciprocating compressor is illustrated. Figure 8 depicts the reciprocating compressor with problem.

Firstly, FM staff receives a manual request of troubleshooting the reciprocating compressor with ID 98241620-001f-49d7-94e9-7104b0a3a93d in the underground floor of

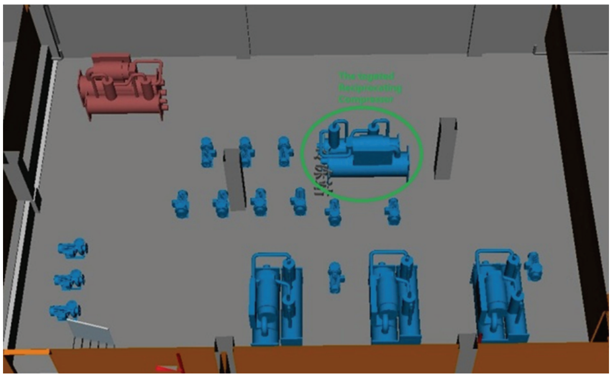

Figure 8: Targeted reciprocating compressor.

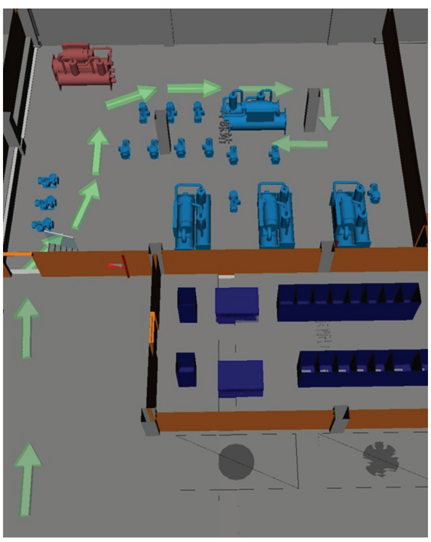

Figure 9: Optimal maintenance travelling path.

the Shanghai Disaster Tolerance Center. He then opens the BIM model and searches with this ID. A section view of Figure 8 is shown, and the targeted reciprocating compressor is highlighted. Access to the maintenance manuals, warranty documents, and maintenance history is also provided in the BIM model. After choosing the action of “go the maintenance site,” an optimal path is visualized which is safe and timesaving as depicted in Figure 9. A third person view is also provided for the simulation of travelling. Arrow keys in keyboard can be used to control the character. Figure 10 depicts the third person view. The FM staff follows the path and troubleshoots the reciprocating compressor with maintenance manuals in a mobile device. Reports are uploaded to BIM central database as history. Status of the reciprocating compressor is updated as “Normal.”

In this case, BIM is utilized as a database and visualization platform to predesign the travelling path in the maintenance job. With knowledge of FM experts, travelling time is well scheduled and reduced, and latent hazards are avoided in the design stage.

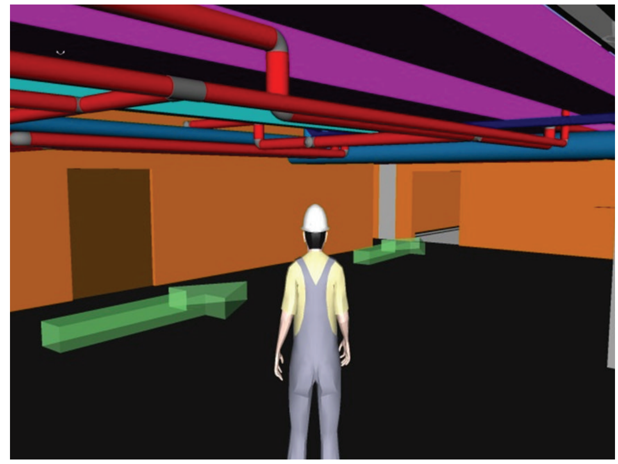

Figure 10: Third person view of travelling.

4. Conclusion and Future Work

This study developed a framework of considering FM in design stage with BIM. The contribution of this paper is the development of an innovative framework, which integrates FM work into early design stage via BIM. Furthermore, one aspect of the whole framework is validated for the proof of the concept. An innovational concept of gathering designers with the FM team through BIM is proposed for strengthening collaboration as well as information sharing and gathering. The purpose is to avoid and reduce the potential issues such as rework and inappropriate allocation of workspace in the operational phase. As little research has identified the approach and benefit of integrating FM with early design stage, this study aims at bridging this gap by providing a working pattern of providing the essential information with BIM. Due to the difficulty of altering the main structure and core service areas in the operational phase, it is practical to design for adaptability by considering operational condition and the facilities’ own attributes. It is very difficult to achieve without the relevant information from FM team and appropriate integration platform. With the ease of access to lifecycle information of all the building components BIM provided, the proposed building plan could be optimized, and lifecycle cost could be reduced with the FM knowledge and experience.

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