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Construction and facility management of large MEP projects using a multi-Scale building information model

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ABSTRACT

Several challenges have been found in the current applications of building information modelling/model (BIM) technology in large-scale mechanical, electrical and plumbing (MEP) projects, such as the huge modelling workloads of MEP models and details, untapped potential in supporting cooperative construction management with multiple participants and insufficient functions for intelligent facility management. This paper proposes a multi-scale solution to address the insufficiencies of the current applications in the construction and facility management of MEP projects. Particularly, a practical multi-scale BIM consisting of several macro-, micro- and schematic-scale information models is described in detail with the required information of the MEP components according to the schema of industrial foundation classes. Based on this model, the paper presents a BIM-based construction management system to provide virtual construction scenes with appropriate scales for various participants to communicate and cooperate, as well as a BIM-based facility management system to share information delivered from previous phases and improve the efficiency and safety of MEP management during the operation and maintenance period. The application in a real-world airport terminal illustrates that the proposed model and two systems can support collaborative construction management and facility management with multi-scale functionalities among participants. This paper proposes a series of feasible models and techniques to promote BIM application in large MEP projects.

1. Introduction

Mechanical, electrical and plumbing (MEP) engineering represent a substantial part of a building and directly influence operating efficiency, safety and energy utilisation [1]. MEP engineering may consist of more than 10 subsystems, including heating, ventilation and air conditioning (HVAC), power distribution, telecommunication, automatic control, fire protection, and water supply and drainage. Each system is a complex combination of several components, such as equipment, pipes and wires, as well as a number of logic relationships among these components.

Particularly for large public buildings such as airport terminals and railway stations, the installation of MEP systems accounts for 20%–40% of the total construction cost and covers more than 50% of the total duration during the construction process [2]. In addition, MEP construction includes many interactive and parallel activities of multiple participants; thus, smooth communication and cooperation among these participants are essential for construction management (CM). Compared with the construction process, the operation and maintenance period takes most of the time within the lifecycle and consequently incurs the highest cost. Among the maintenance tasks, the operation management of MEP components has a critical role, and the cost could account for up to 60% of the total cost [3].

Building information modelling/model (BIM) systems provide all of the participants with a shared information source and several visualisation platforms. BIM systems effectively assist managers in conducting collaborative CM. Furthermore, the application of BIM can provide managers with structured information to support the rapid querying of required information on MEP assets and 2D/3D virtual scenes for facility management (FM) [4].

Although the BIM concept has been proposed for many years, several studies on their applications to the CM and FM of large-scale MEP projects point out some deficiencies in the current practices. For example, inconsistent/time-consuming manual modelling is one of the deficiencies to limit BIM Model development [5] and

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the high LOD[1] is not compatible with current time and cost restrictions in the architecture, engineering, construction, facility management and deconstruction (AEC/FM/D) engineering [6]. The chosen LOD for a given task should be determined by the purpose of its usage, considering the impacts as well as benefits of a LOD [7]. Generally speaking, the MEP engineering of a large public building includes more than 10 systems, each of which has dozens of thousands of components. Modelling all of these components in detail and importing them into a single system for visualised CM or FM are impossible because of the numerous elements embodied in MEP systems. In fact, modelling the entire details for all of the components is always unnecessary because in certain cases, a schematic or rough model is adequately informative and lightweight to assist CM and FM. Another deficiency limiting the application of BIM is the lack of functions to support remote collaboration [8]. More than 10 constructors may be involved in a large-scale MEP project and thus work synchronously in the same area. In addition to quick modelling functions, facilitating communication and cooperation among participants is crucial to avoid construction conflicts and other problems. Finally, though BIM normally comprises building geometry, spatial relationships, and quantities and properties of building components [9], some specific logic relations among BIM components are excluded [6]. Considerable commercial software facilitates FM utilising 3D virtual environment and BIM, however with no further logic relationships embedded and because of the great number of entities in a large MEP project, FM functions are insufficient and the display efficiency is typically unacceptable.

By investigating the common requirements for large MEP projects utilising BIM, this research proposes a multi-scale solution for both CM and FM of large MEP projects. Particularly, a possible multi-scale BIM that consists of macro-, micro- and schematic-scale models for CM, as well as micro- and macro-scale models for FM is presented with the details of its architecture and its representation compliant to the industry foundation classes (IFC) [10]. Based on this multi-scale BIM, a CM system and an FM system for MEP engineering are developed. Finally, the paper examines and discusses the in-depth application to the MEP project of a large real-world airport terminal, the Kunming Changshui International Airport terminal.

2. Related research

A BIM contains a variety of relevant engineering data of a building [11]. Through the establishment of a single project data source, BIM technology aims to achieve the integration of distributed, heterogeneous engineering data and to support information sharing and collaboration among various participants and different phases within the building lifecycle.

BIM is extensively adopted during the design phase of MEP systems. For example, a prototype tool based on an MEP knowledge database and BIM has been developed for automatically detecting clash and facilitating MEP coordination [1,10]. Researchers have indicated that establishing detailed models with appropriate attributions and fineness is critically important for collaborative design [12].

BIM technologies for CM include quantity take-off, cost estimation [13], construction safety analysis [14], workspace conflict [15] and four-dimensional (4D) CM [14,16] with various functions, such as construction simulation, schedule management, resource and cost management and site management. Russell [17] and Staub-French [18] introduced linear scheduling into 4D CM because of its insufficiency in visualising relationships among tasks in large-scale linear projects. Kuo [19] comprehensively employed the Gantt chart, network diagram, tree structure view and 3D graphics platform in visualising temporal, relational, hierarchical and spatial information to support the CM of multiple systems. Some researchers successfully applied BIM to MEP construction, for instance, by proposing a method for drawing up the transporting and installing programme of MEP elements according to their size, weight and other information extracted from BIM [20], or by creating MEP 3D/4D models to aid in MEP collaborative design and construction [21,22]. These studies also summarized the guidelines for creating MEP 3D/4D models and suggested the importance of clarifying modelling requirements and the levels of detail.

For BIM applications in the operation and maintenance phase, data description standards, such as an FM data model FMC [23] an object-oriented product model utilising unified modelling language (UML) use cases [24], were presented to assist facility managers in managing lifecycle information more effectively. An extension of IFC, including FM information (i.e. performance requirements, conditions and inspection) and repair information of MEP assets [25] has been established. Researchers have developed a few FM systems, including a 3D visualisation of buildings for FM with a method of reusing BIM created in previous phases through Ifcxml files [26], an FM system according to some existing problems such as tedious and error-prone tasks in practice [27] and an integrated system for capturing information and knowledge of building maintenance operation to support preventive or corrective operations by understanding how a building is decorating [28]. On the other hand, a prototype of a BIM-based game system that integrates BIM and game environment has been developed for interactive visualisation [29]. IFC files were used as input for path planning to facilitate the sharing of both geometric information and rich semantic information on building components [30]. These studies have laid the foundation for indoor path planning during the operation and maintenance period. An investigation showed that facility managers agreed that the application of BIM in FM could save information query and management time, but the extra investment and work process changes would hinder the application to a certain degree [31].

To identify the processes that are undertaken within a project and the corresponding information required by each process, buildingSMART proposed the information delivery manual (IDM) [32] approach to support the IFC-specified information. Model-view-definition (MVD) [33] provides a formal process for specifying the mappings between the IFC schema and the information requirements in different domains to address the standardization of such model subsets [34]. Particularly for identifying the information requirements for the performance analysis of HVAC systems, Liu [35] introduced an improved IDM approach for mapping information requirements to multiple information sources that use various formats and schemas. Construction operation building information exchange (COBie) [36] was developed to provide a specification for final information delivery to the operation and maintenance phase. COBie also uses MVD to represent mappings between its information requirements and the IFC data model. Most of these approaches are utilised in service-oriented architectures to facilitate the remote access of model repositories through standardised network protocols [37–39]. These achievements enable data sharing between various participants within different phases of a project.

Even though BIM brings many benefits to the AEC industry, problems and barriers still exist to accept BIM without discomfort [40]. For example, IFC is a rich product-modelling schema,

[1] LOD (Level of Details) refers to the detail of a model, describing a BIM component from the lowest conceptual design level to the highest as-built modelling level. There are 5 levels: LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 refer to conceptual design model, developed design model, presentation and bidding model, construction model and as-built model, respectively.