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WBS-based dynamic multi-dimensional BIM database for total construction as-built documentation

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ABSTRACT

As-built documentation is valuable to assist decision-making in project control, and building operation and maintenance applications. Given the importance of as-built documentation, the quickly maturing technology of building information modeling (BIM), an object-oriented information-integration platform, has led to the emergence of concurrent as-built documentation during the construction phase. However, in the current practice, integrating construction records into BIM remains a challenge due to their heterogeneous and unstructured data formats. This paper presents a work breakdown structure (WBS)-based database design to enable the creation of a dynamic multi-dimensional BIM database to incorporate construction records in a timely manner. In this study, the construction records were defined as additional dimension, and a WBS code-based automated linking mechanism between construction project tasks and BIM objects was created to generate the multi-dimensional BIM database. The automatic linking mechanism and the WBS-based dynamic multi-dimensional BIM database were tested and verified through the implementation of a real construction project schedule and a BIM model. The test results illustrate that the newly created method is successful in incorporating construction records collected during the construction phase to generate a dynamic BIM database for generating complete as-built documentation.

1. Introduction

As-built documentation that captures construction records, generated as the construction phase progresses [1,2], has great value in progress tracking, scheduling, and decision-making during the construction phase, and the later operation and maintenance of projects [3]. Abdel-Monem and Hegazy [4] mentioned that construction records for as-built documentation are collected from voices, emails, and text messages to enhance the progress tracking of projects. Li and Poon [5] specified that construction process information included in the construction records is useful for decision-making of safety management in construction site. Goedert and Meadati [6] described that construction records (e.g., schedules, request for information—RFI, change orders, submittals, and shop drawings) in the as-built documentation are a key component for the successful building management during the operation and maintenance (O&M) phase. Motawa and Almarshad [7] mentioned that certain information in the construction records (e.g., construction method, information about contractors, ripple effect on the other building elements, and quantities and costs of components and materials) improve the operations of building maintenance tasks.

During the construction phase, a large number of construction records (e.g., schedules, construction methods, cost data, daily reports, site photos, shop drawings, and change orders) are generated; however, such data are not included properly in the current as-built documentation [3]. Inaccurate and incomplete as-built documentation during the construction phase contributes to misunderstanding, lack of early warning, project delays, and cost overruns [4]. Moreover, the lack of complete as-built documentation after the completion of construction leads to information delays in the operations and building management tasks [8]. Consequently, huge amounts of time and money are wasted on non-value-adding tasks, such as searching and verifying as-built documentation during the O&M phase [3,8].

Given the importance of complete as-built documentation, several recent BIM-based construction projects [2,9–11] have recommended generating concurrent as-built documentation during the construction phase, and specified that complete as-built documentation for projects is the integration of timely collected construction records with 3D BIM. In particular, the application of BIM for infrastructure construction projects is rapidly accelerating in the architecture, engineering, and construction (AEC) industries [12], and construction records (e.g., cost information, field test results, and inspection procedures and results)

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are a significant component for the management tasks of infrastructure [13]. Thus, the increasing needs of concurrent as-built documentation integrating with the construction records in the recent BIM-based projects are a natural movement. To meet this aim, Goedert and Meadati [6] and Meadati [14] directly integrated 2D document-based construction records (e.g., schedules, specifications, RFI, change orders, submittals, and shop drawings) into individual 3D BIM objects. Using Autodesk Revit, they generated extra attributes in each 3D BIM object and recorded the file path information of the relevant 2D document-based construction records. Moreover, Wu and Hsieh [15] and Ding et al. [16] presented frameworks to link the latest construction records with each 3D BIM object using multi-dimensional (nD) modeling technology. Specifically, they defined construction records as additional dimension and presented methodologies to integrate or link construction records with individual 3D BIM objects.

One thing the aforementioned research has in common is that the integration of the construction records is centered on the individual 3D BIM objects. However, current object-centered methods present some significant limitations on the integration of construction records. First, 3D BIM models can be developed as multiple files (e.g., architectural, civil, and structural models), and each model file can be updated continuously during the construction phase. Moreover, as BIM models are focused on the description of end products [17], thus, objects related to certain tasks (e.g., temporary and demolition works) are not described in BIM models. Consequently, integrated construction records in each 3D BIM object can be scattered, duplicated, or omitted among the different types and versions of 3D BIM model files, and this can lead to time-consuming and inefficient operations for searching and validating information [18]. Second, most of the aforementioned studies [6,14,16] are based on conventional file-based management methodology, which can cause data inconsistency between project participants [19]. Thus, project participants might use different versions of 3D BIM model files to integrate construction records into 3D BIM model files, and there is no guarantee that all project participants will use the same file versions.

As an alternative to these BIM-based approaches, a work breakdown structure (WBS)-based centralized database can eliminate the aforementioned limitations, because WBS is the basis of construction project management [20], and it can be used as the centerpiece of construction record management [21]. Moreover, the data inconsistency issue among project participants can be resolved using a centralized database [19]. For example, Wang et al. [21] developed a WBS-based information model using Web and database technologies to manage construction information, and proved that a WBS-centered structure can successfully combine cost, time, and other construction records in a timely manner. This suggests that the WBS-based centralized database structure is more appropriate to integrate 3D BIM and construction records than the current 3D BIM model objects-based and file-based methodologies for generating complete and concurrent as-built documentation.

The main objective of this study is to develop a WBS-based dynamic nD BIM database structure to ensure that the total construction as-built documentation contains all construction records in a timely manner during the construction phases. Construction records (e.g., schedules, cost information, RFI, change orders, daily reports, and video clips) are defined as additional dimension and are integrated with the 3D BIM centered on the WBS. The remainder of this paper is organized as follows. First, relevant technologies and concepts are reviewed for developing the proposed WBS-based nD BIM database structure. Subsequently, the proposed database structure is explained in detail. Specifically, the WBS code structure and the automatic linking mechanism between WBS code-based project tasks and 3D BIM model objects are proposed and tested through an implementation of a real construction project schedule and a BIM model. Finally, the conclusions of this study are reported.

2. Literature review

This section summarizes the concept of the nD BIM and the dynamic BIM to develop a WBS-based dynamic nD BIM database.

2.1. Multi-dimensional (nD) BIM

The concept of the nD model was introduced in the “3D to nD Modelling” research in the Research Institute for the Built and Human Environment (BuHu) at the University of Salford [15,16,22], and the nD model or nD BIM has been defined as an extension of 3D BIM [23,24]. nD BIM is a significant component in the future of construction project management [15] - it provides project participants a database to retrieve and share project information through the same platform during the whole project lifecycle [22]. Under this background, many researchers have made various attempts to expand 3D BIM to nD BIM. Generally, 4D BIM links time information and data in the 3D BIM, 5D BIM integrates all of the information regarding cost and time data, and 6D BIM integrates all project lifecycle information to BIM [24]. Regarding sixth dimension, various approaches have been proposed recently. At the very beginning, O'Keeffe has proposed that a sixth dimension is energy, and he developed a unified nD framework and process to expand 3D BIM to nD BIM [25,26]. Moreover, Zhou et al. [27] have suggested that safety information is a sixth dimension, and they developed an information system to visualize integrated data. As another perspective, Wu and Hsieh [15] and Ding et al. [16] defined construction records (e.g., quality information, health and safety information, and contract information) as a sixth dimension based on 5D BIM concept, and presented frameworks to expand 3D BIM to nD BIM. In a similar way, the study presented in this paper also defines construction records as a sixth dimension. However, unlike the previous studies, this study uses WBS rather than 3D BIM objects as the centerpiece of nD BIM.

2.2. Dynamic BIM

The dynamic BIM concept has been explored by several researchers over the past few years [27–29]. A dynamic BIM contains timely building information, which enables rapid decision-making and timely responsiveness to emergencies. Moreover, it has the potential to provide improved documentation and optimized building operation and maintenance [29,31]. Current research efforts have been focusing on embedding data obtained from various types of sensors. For example, Cahill et al. [28] investigated how a dynamic BIM can be supported by integrating sensor data, and Chen et al. [29] introduced an approach to connect the sensor data and the Industry Foundation Classes (IFC)-based BIM model. In addition, Srinivasan et al. [30] discussed integrating the analysis results of 3D heat transfer into a BIM model, and van Berlo et al. [32] proved the technical feasibility of linking static BIM data and dynamic data from sensors by conducting several experiments. They used the IfcSensor attribute of the IFC file format and the open building information xchange (oBIX) in their experiments, and they achieved 100% open source-based environments for the dynamic BIM. Therefore, it is anticipated that the WBS-based dynamic nD BIM database will be compatible for continuous integration and visualization with timely construction records in a similar way.

3. WBS-based dynamic nD BIM database structure

This section describes the proposed WBS-based dynamic nD BIM database design. The overall structure of the proposed database is presented first, and then each relationship between entities is illustrated in detail.