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Bridging BIM and building: From a literature review to an integrated conceptual framework

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Abstract

A Building Information Model (BIM) is at risk of being 'blind and deaf' if its contained information cannot be synchronized with ongoing building processes in a real-time manner. Previous studies have attempted to explore solutions to the problem, with a view to making BIM a more useful decision-support system. However, an integrated conceptual framework summarizing these studies and structuring future development in the area is missing. Based on an *ex post facto* critical review of 75 papers of this kind published over the past decade, this paper proposes a conceptual framework for bridging BIM and building (BBB), which highlights the importance of synchronizing information between BIM and real-life building processes. The framework is further illustrated through a case study of prefabricated housing construction in Hong Kong. With this integrated conceptual framework, future research on BBB can proceed on a more solid footing.

Keywords: Construction project management; Building Information Modeling (BIM); Information and communication technologies; Literature review; Conceptual framework

1. Introduction

The importance of information in contemporary construction project management cannot be overemphasized. Managing a construction project involves using available information and knowledge to make a web of decisions across processes including architecture, engineering, construction, and operation (AECO) (Flanagan and Lu, 2008). A comprehensive taxonomy of information in regard to construction project management is yet to be defined; however, it normally comprises building geometry, spatial relationships, and quantities and properties of building components (Pratt, 2004). Lu et al. (2013) identify information as a new element in construction project management, a view which has encouraged the authors' own theoretical stance that a building can, in fact, be perceived of as a cluster of information, the management of which can achieve better AECO performance. It has become a truism that the main objective of information management is to support decision-making by ensuring that accurate information is always available at the right time in the right format to the right person, and it is against this backdrop that the development of Building Information Modeling (BIM) has gained momentum.

According to the U.S. National BIM Standard (2007), BIM is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle" (p.149). Eastman et al. (2008), on the other hand, intentionally and consistently use the term 'BIM' to describe the activity of modeling building information. In this study, we use 'BIM' to refer to both the activity of modeling and the digital and virtual representation/model of a physical building.

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BIM has been adopted by an increasing number of AECO firms to manage project information and support information sharing between stakeholders (Goedert and Meadati, 2008); gradually, it is becoming an indispensable information platform for decision-making in construction. Nevertheless, in current practice, a BIM is largely disconnected from the real-life physical building processes throughout its life-cycle. For example, an architectural or structural model, however it is detailed by architects or engineers, will remain static if the information contained within it cannot be synchronized with the ongoing building process. A BIM is thus at risk of being 'blind and deaf' to ongoing AECO processes, while an 'as-built' model can more reliably and usefully support information exchange and decision-making throughout the project life-cycle. Manually updating information in a BIM in line with the physical building process has been found to be interruptive, tedious (Li et al., 2009), time-consuming and error-prone (Anil et al., 2013). To this end, researchers around the world have attempted to develop methods and technologies such as Auto-ID to facilitate the integration of virtual models and physical construction (e.g. Flanagan et al., 2014).

What seems to be lacking, however, is a conceptual framework highlighting the theoretical perspective of bridging BIM and building (BBB), which means connecting the information contained in BIM with physical building processes to make BIM reflecting real-life situations. Such a framework could help summarize research work in BBB, which has developed in a piecemeal fashion to date. It could also make it possible to theorize a building as a cluster of information; BBB, currently performed via different information and communication technologies (ICTs), has actually become a general research question at the fore of information management (IM) for decision-making in contemporary project management. Further, an integrated conceptual framework would help structure strategic development directions in this area, allowing future research on bridging BIM and building to proceed on a more solid footing.

The aim of this research, therefore, is to develop a conceptual framework that: (1) summarizes the research work related to BBB; (2) highlights the concept of bridging BIM and building; and (3) structures the future directions of research work in this area. It does so by critically reviewing a body of literature comprising 75 papers published in six academic journals over the past decade. Based on the literature review, a conceptual framework is developed and illustrated using a case study. The rest of this paper is structured as follows. The research method of this study is elaborated in Section 2. The results of the literature review are presented in Section 3. Based on the results, the conceptual framework for BBB is developed and presented in Section 4. Section 5 is a case study of the use of radio frequency identification (RFID)-enabled BIM in prefabricated housing production in Hong Kong to illustrate the critical issues in BBB. Sections 6 and 7 comprise the discussion and conclusions respectively.

2. Research methods

As previous studies have touched upon issues relating to bridging BIM and building (BBB), the development of the conceptual model of BBB starts with a critical literature review. Literature review is defined as "a systematic, explicit, and reproducible method for identifying, evaluating, and interpreting the existing body of recorded work" (Fink, 1998, p.3). It develops the connection between related research works, and helps to identify the current achievement in a specific field and highlight important issues to be solved (Cooper, 1998). Given the difficulty of searching every related research work, delimitation to determine the boundary of the research is often necessary. Here, three criteria were considered during delimitation of the BBB literature:

(1) Only papers in peer-reviewed English journals are reviewed;
(2) The topic of the papers should be strictly limited to the use of virtual models with real-life project information; and
(3) Papers on construction informatics, which describe data acquisition from the physical environment but have no relationship to the virtual models, are excluded.

According to our criteria, six journals are selected, namely, *International Journal of Project Management*, *Automation in Construction*, *ASCE Journal of Construction Engineering and Management*, *ASCE Journal of Computing in Civil Engineering*, *Journal of Information Technology in Construction*, and *Engineering, Construction and Architectural Management*. All the six journals have published at least one article fitting the criteria and are highly ranked by construction informatics researchers. The keywords used for searching the relevant papers included 'BIM', 'virtual design and construction (VDC)', "as-built" model, and 'virtual model'. The contents of each paper were quickly screened by one of the authors to identify whether they should be included or excluded. To decrease potential bias during selection of journal papers, another author double-checked the selected papers. After delimitation, a total of 75 papers published from 2005 to 2014 were identified and considered as recent work.

Preliminary analyses were conducted to determine the basic descriptive information of each selected paper; that is, year of publication, research targets including applications and stages of the project life-cycle, and technologies used to connect the virtual model with physical projects. These descriptive results helped to group the papers before detailed analysis. The advantages and limitations of all possible technologies or methods and their scopes of application were critically analyzed with a view to providing components of the conceptual framework of BBB. The conceptual framework was subsequently evaluated through a case study, feedback from which enhanced the conceptualization of BBB (Fig. 1).

3. Results of literature review

3.1. General descriptions of the literature

The first study hit by the 'selection of papers' is Kim et al. (2005), which explores a rapid modeling method to transform data collected by laser range finder to decision-supporting information in the virtual model. Research relating to bridging BIM and building (BBB) has gained momentum, as witnessed increasing publications after 2005. This upward trend shown in