Automation in Construction 46 (2014) 82–93

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD

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ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form 19 March 2014
Accepted 14 April 2014
Available online 5 May 2014

Keywords:
BIM
3D
nD
Computable
Modeling

ABSTRACT

The utilization of Building Information Modeling (BIM) has been growing significantly and translating into the support of various tasks within the construction industry. In relation to such a growth, many approaches that leverage dimensions of information stored in BIM model are being developed. Through this, it is possible to allow all stakeholders to retrieve and generate information from the same model, enabling them to work cohesively. To identify gaps of existing work and evaluate new studies in this area, a BIM application framework is developed and discussed in this paper. Such a framework gives an overview of BIM applications in the construction industry. A literature review, within this framework, has been conducted and the result reveals a research gap for BIM applications in the project domains of quality, safety and environmental management. A computable multi-dimensional (nD) model is difficult to establish in these areas because with continuously changing conditions, the decision making rules for evaluating whether an individual component is considered good quality, or whether a construction site is safe, also vary as the construction progresses. A process of expanding from 3D to computable nD models, specifically, a possible way to integrate safety, quality and carbon emission variables into BIM during the construction phase of a project is explained in this paper. As examples, the processes of utilizing nD models on real construction sites are described. It is believed to benefit the industry by providing a computable BIM and enabling all project participants to extract any information required for decision making. Finally, the framework is used to identify areas to extend BIM research.

1. Introduction

Many researchers have evaluated the effectiveness of Building Information Modeling (BIM) applications within different educational or industrial settings [1]. In addition, many practitioners have acknowledged the potential benefits of this new technology, such as Sacks et al. [2], Chen et al. [3] and others [4,5]. To date, BIM is accepted as a process and corresponding technology to improve the efficiency and effectiveness of delivering a project from inception to operation/maintenance [6]. In the last decade, BIM has received a considerable amount of attention by researchers. A number of case studies have been published that show useful BIM implementations on actual construction projects. In *The BIM Handbook*, 10 case studies have been thoroughly explained [7]. In addition, Hartmann and Fischer proposed to use 3D/4D models for design review from the perspective of constructability [8]. Rüppel and Schatz designed a BIM-based game for fire evacuation simulations [9]. Zhou and Ding presented a 4D visualization technology for safety management [10]. Case studies such as these have served as a starting point for practitioners to better understand how BIM can be applied on their projects.

From a previous research review, it is seen that utilization of BIM in the construction industry can help practitioners by improving visualization, communication and integration in construction operations [11]. However, some practitioners still hesitate to adopt these innovative tools [12]. Some surveys have been conducted to evaluate the extent and benefits of applying BIM in the construction industry in different countries [13–16]. According to the survey conducted by Young, architectural/engineering/construction (A/E/C) participants did not identify much value in using BIM [12]. Therefore, a framework is needed to understand the clusters of work and less focused areas to push the research on and utilization of BIM throughout the life-cycle of facilities for multiple stakeholders. A well-rounded BIM application framework might give the practitioners a broader view of the use of BIM applications to support construction project management and help them to better understand the benefits of implementing BIM on their projects.

Formulating a comprehensive framework provides an opportunity for the researchers to identify future BIM research and implementation directions and it would enable application of these sophisticated technologies in the whole life-cycle of projects [17,18]. This paper offers a starting point for the development of such a framework. It

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http://dx.doi.org/10.1016/j.autcon.2014.04.009
0926-5805/

presents a framework of BIM applications generated from past project implementations of BIM. The framework would guide research efforts, which will enhance communications, share understanding and knowledge growth among all the academic researchers and industry practitioners, and integrate relevant concepts into a descriptive or predictive model. A thorough literature review has been conducted to validate the framework and identify the current research gap. The process of how BIM applications expand from 3D to nD, specifically referring to quality, safety and environmental management in this paper, is described.

Such a framework would guide practitioners to applications of this new technology and show researchers where the development of deeper knowledge and better tools is needed. In addition, the main challenges of implementing BIM applications with potential solutions are explained. The authors hope that this paper will inspire further development of the research framework and guide future research into BIM applications.

2. Terms and definitions

Building Information Modeling (BIM) is defined as “a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition [19].”

Many terms related to BIM have been adopted by researchers, such as virtual design and construction (VDC) and multi-dimensional (nD) modeling. Table 1 lists some of the widely used terms in both research and industry studies and shows a summary of them by application domain.

A BIM model is different from traditional 3D CAD models in which 3D CAD only describes a facility with independent 3D views, such as plans, sections and elevations. If one of those views is modified, the others must be updated accordingly. Further, data in 3D CAD drawings are only graphical entities, such as lines, arcs and circles. On the contrary, a BIM integrates semantically rich information related to the facility, including all geometric and functional properties during the whole life cycle in a collection of “smart objects” [20]. For example, a valve or tube module within a BIM would also include its functional and performance properties, such as material, supplier, maintenance requirements, cost and delivery time, in a semantically rich way. Each component is a “smart object” with all associated parameters stored in it. The information of the properties can be accessed when needed by any stakeholder. This important feature of BIM allows stakeholder access to information and combinations of information to which they have never before easy access.

As for other terms, virtual reality (VR) provides a tool which allows a user to experience a computer-generated simulation of a real or imagined environment [21–23]. 4D modeling utilizes BIM for project time allocation and construction sequence scheduling simulations while VDC is becoming a more accepted industry term to explain the use of BIM to design and construct a project [37].

In terms of nD modeling, some researchers use nD to describe the different maturity levels of BIM [38]. Some researchers define nD as an extension of BIM [32,39]. Although some have tried to differentiate nD from BIM [40], most research has agreed that BIM represents the utilization of nD models to simulate the planning, design, construction and operation of a facility [39,41].

Application of BIM can be described as a process that expands 3D data into an nD information model, which allows dynamic and virtual analysis of *scheduling* [42–45], *costing* [46,47], *stability* [48,49], *sustainability* [50,51], *maintainability* [52], *evacuation simulation* [9,53] and *safety* [54] to name a few. This nD model provides a database allowing all stakeholders to retrieve needed information through the same system, which allows them to work cohesively and efficiently during the whole project life-cycle. Therefore, to be useful to academic researchers and industry practitioners, a BIM application framework must contain three parts: all project management domains (examples are listed above in italics), all stakeholders, and across the whole project life-cycle. The three parts of the framework are defined in the following sections (Sections 3 and 4).

3. BIM application framework

3.1. Overview

This section introduces the proposed BIM application framework, a research and delivery map of existing research and implementation projects which identify interrelationships between project domains and requirements for further knowledge acquisition. This proposed BIM application framework targets stakeholders to better understand the current state of BIM applications and future BIM implementation requirements.

A BIM framework must be comprehensive enough to address all relevant BIM domains and implementation challenges as well as to present key issues of project management in a systematic manner. On the basis of the definition of BIM, this application framework consists of three parts: 1) project domains listed, 2) stakeholders and 3) phases of the project life-cycle. These are shown as the three axes in Fig. 1.

A particular research can be put in this framework using one of these six options: 1) single BIM application within a single organization through a single project phase; 2) single application within multiple organizations through a single phase; 3) single application within multiple organizations through multiple phases; 4) multiple applications within a single organization through a single project phase; 5) multiple applications within a single organization through multiple project phases and 6) multiple applications within multiple organizations through multiple phases.

For example, as shown in Fig. 2, “$a_1a_2a_3a_4$” represents the utilization of BIM for safety management from the owner's perspective, while “$b_1b_2b_3b_4$” represents the utilization of BIM for cost management from the perspective of different stakeholders, which are, in this case, the owner, the contractors and the supervisors, also known as owner's representatives. The “$c_1c_2c_3c_4,$ $d_1d_2d_3d_4$” area represents the utilization of BIM for design review during the planning and design phases by different stakeholders. In this framework, application of BIM in the construction industry can have 6 different levels based on the project

Table 1
Differences between widely used terms and BIM.

Sample terms	Information can be retrieved from 3D building elements	Design review	Performance simulation	Virtual simulation of construction process	Management of site constraints	Maintain facility operations	Reference
3D CAD		√					[20,21]
Virtual reality (VR)				√	√		[21–24]
4D modeling	√			√	√		[25–28]
VDC	√	√	√	√	√		[29–31]
nD modeling	√	√	√	√	√	√	[32,33,39]
BIM	√	√	√	√	√	√	[7,97]

Other related terms: Integrated project delivery [34], computer integrated construction [35], building product models [36].