



A LITERATURE REVIEW OF THE FACTORS LIMITING THE APPLICATION OF BIM IN THE CONSTRUCTION INDUSTRY

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Abstract. Building Information Modeling (BIM) has had a profound effect on the construction industry. It has greatly improved coordination among stakeholders, enhanced productivity, and increased profits. However, many factors still limit the application of BIM in the construction industry. This study conducts a literature review to identify these negative factors. Firstly, twenty-two sub-factors are identified and classified into five categories: Technology, Cost, Management, Personnel, and Legal. Secondly, some suggestions for eliminating these limiting factors are given. Finally, the study also identifies further research directions for improving BIM theory and applying BIM technology widely and successfully. The results of this study will provide support for practitioners who are using or plan to use BIM.

Keywords: building information modeling, BIM, construction industry.

JEL Classification: L74, L86, O14, O33.

Introduction

Building Information Modeling (BIM) technology is changing the construction industry. It is the future of the AEC industry (Hoffer 2008). Market research from National Institute of Building Sciences (NIBS 2007) shows that future building design and construction will increasingly rely on BIM. Currently, BIM is being applied in many stages of the construction project lifecycle, creating significant benefits for the stakeholders and society. For instance, the design team at the General Motors Production Plant in Flint, Michigan, estimates that the use of BIM technology, specifically automated clash detection, saved 3–5% in overall

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costs, and the 3D digital workflow contributed an additional 2–4% in cost and time savings (Eastman *et al.* 2008). Another project, the Hilton Aquarium in Atlanta, Georgia, used BIM for design coordination, clash detection, and work sequencing. The cost of the BIM was \$90,000, 0.2% of the project budget (\$40,000 paid by owner), and the cost benefit was \$600,000. Most of the savings were from the elimination of clashes, resulting in 1,143 saved hours (Azhar *et al.* 2011). Furthermore, a web survey conducted by Autodesk (2008) suggests that BIM increases productivity after an average of three to four months, is more accessible than general CAD applications, enhances workflow after training, benefits owners, designers, and contractors, reduces the risk of design error, and enables communication and coordination among the project team. Although BIM has many benefits, there are also limitations and barriers that have slowed BIM application (Yan, Damian 2008; Zhang, Gao 2013), and BIM application is still in an infant stage to some extent (Cao *et al.* 2015).

This study uses a literature review to identify the factors limiting the application of BIM in the construction industry, sets up a detailed classification of these limiting factors, and presents some suggestions for their management or avoidance. The research results will encourage the wider application of BIM in the construction industry.

1. BIM

1.1. Definition of BIM

BIM, as a popular term, is not new. The concept, approaches, and methodologies that we now identify same as BIM have been studied for many years. One of the early documented example is a working prototype, the Building Description System presented by the “father of BIM,” Chuck Eastman (Eastman *et al.* 2008) in 1975. Since then, although most researchers and organizations have focused on CAD-related studies due to the successful application of CAD in the construction industry, there have been many studies of BIM-related technologies, especially in the last decade. As a result of the variety in understandings of intelligent building and research emphases, many new terms relating to BIM have been developed. Bilal Succar (2009) identifies some of the more widely used terms in both the research and industry literature: Asset Lifecycle Information System, Building Product Models, BuildingSMART™, Integrated Design Systems, Integrated Project Delivery, nD Modeling, Virtual Building™, Virtual Design and Construction, and 4D Product Models. Even the term BIM, popularized in 2002 by Jerry Laiserin (2002), has no widely accepted definition. Table 1 sets out some of the more important definitions.

Table 1 demonstrates that most definitions of BIM use it as a term to describe a modeling process or activity rather than a model. In addition, the characteristics of BIM can be seen in the following definitions.

- It is a group of datasets that together contain all of the information about a building; these data can be shared and used in the lifecycle of a project by all of the stakeholders.
- It is a modeling technology and an integrated process used to create a building information model; this model is an intelligent and parametric digital representation of the building.

Table 1. BIM definitions

Organization or Researcher	Definition
NIBS (2007)	A digital representation of the physical and functional characteristics of a facility, which serves as a shared knowledge resource for information about a facility that forms a reliable basis for decisions during its lifecycle from inception onward.
GSA (2007)	BIM is the development and use of a multi-faceted computer-software data model that not only documents a building design, but simulates the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting model is a data-rich, object-based, intelligent, and parametric digital representation of the facility from which views appropriate to various users' needs can be extracted and analyzed to generate feedback on and improvement of the facility design.
Eastman <i>et al.</i> (2008)	A modeling technology and associated set of processes for producing, communicating, and analyzing building models.
Harness (2008)	A building information model (the model) is a digital representation of the physical and functional characteristics of the project. BIM is the process and technology used to create the model.
Autodesk (2012)	BIM is an integrated process that vastly improves project understanding and allows for predictable outcomes. This visibility enables all of the project team members to stay coordinated, improve accuracy, reduce waste, and make informed decisions earlier in the process – helping to ensure the project's success.
Tekla (2013)	The process of modeling and communicating the structure of a building in detail to benefit the entire building lifecycle.

- It can greatly benefit the entire building lifecycle, such as improving communication, coordination, collaboration, and cooperation, reducing building waste, and forming a reliable basis for decisions.

In this paper, for avoiding the confusion about the abbreviation of BIM, we use the term “BIM” to refer to the processes of modeling, collaboration and integration and “building information model” to refer to the object-based model or a group of datasets.

1.2. BIM uses in the construction industry

BIM can be applied to every stage of a construction project from inception to demolition (Autodesk 2002; Eastman *et al.* 2008; Azhar *et al.* 2011).

- Visualization: 3D views, renderings, and walk-throughs can be easily generated.
- Change management: change to any part of a building is automatically coordinated in all of the other parts.
- Code Checking: the building information models can be used by municipal building departments for the approval of building projects.
- Clash Detection: as building information models are created early in the process, all of the major systems, such as piping, plumbing, construction equipment, and sheet metal ductwork can be visually checked for time-space conflicts in the preconstruction phase.

- Fabrication: all of the shop drawings of the building systems for the fabricators can be more easily and quickly produced from the building information models than traditional mode.
- Communication and collaboration: all of the information on the participants, building materials, building machinery, planning, and everything else is incorporated into the building information model so that communication and collaboration between stakeholders can be supported through one consistent model.
- Time and cost management: 4D and 5D are model-based deliverables, which can be used for activities such as constructability analysis, project delivery schedules, material requirement planning, and cost estimating.
- Green building: building information models can be transferred into other software programs for further analysis of the building's comfort, lighting, energy performance, etc.
- Facilities management: BIM can be used for space management and maintenance operations in facilities management.

1.3. Benefits of BIM

Many scholars have studied the benefits of BIM for the AEC/FM industry. For example, Chuck Eastman *et al.* (2008) discuss the benefits at each of the four construction stages: pre-construction, design, construction and fabrication, and post-construction, although some of the benefits they discuss are not currently available but can be expected as BIM technology develops. Salman Azhar *et al.* (2011) summarize eight kinds of benefits: accurate geometrical representation, faster and more effective processes, better design, controlled whole-life costs and environmental data, better production quality, automated assembly, better customer service, and lifecycle data. Case studies of construction projects that use BIM indicate that there are 8–15% savings on new projects and up to 35% savings on repeat projects; these savings are the result of reusing information, having more (and better) decision-making information earlier, and better early-phase analysis (Jernigan 2007).

Previous studies suggest that the application of BIM has the following benefits (Gilligan, Kunz 2007; Azhar *et al.* 2008, 2011; Nisbet, Dinesen 2010; German 2012):

- reducing costs and improving the accuracy and speed of cost estimates;
- avoiding clashes (up to 10% of the contract value is saved by detecting clashes);
- shortening time (up to 7% reduction in project time);
- ensuring lower whole-life costs for the asset through sustainable design;
- facilitating construction coordination;
- reducing requests for information and change orders (up to 40% elimination of un-budgeted change);
- facilitating generation of construction documents;
- facilitating the simulation and visualization of the construction project.

2. Research methodology

To collect and review the previous research related to the factors limiting the application of BIM, a typical literature review is adopted. The research procedure consists of three steps:

The first step is collecting as many relevant studies as possible. Two search conditions are used. Due to the nonexclusive definitions of BIM, the terms in the first search condition are “Building Information Modeling” or “BIM” or “Building Information Model” or “Virtual Design and Construction” or “4D” or “nD”. There are many synonyms for “factors limiting the application”, so the second search condition includes the terms “barrier”, “inhibit”, “drawback”, “obstacle”, “flaw”, or “impediment”. The search encompasses many types of resources including books, reports, journal/conference databases, and websites. The journal/conference databases are the EI Village (Compendex), ASCE library, Elsevier Science, Science Citation Index (Web of Science), etc. The reports are from well-known companies that have developed BIM tools, such as Autodesk®, Graphisoft®, and Bentley®. For collecting as many studies as possible, after an initial set of studies is identified by using keywords, the references in these studies is used as the starting point to find other studies.

The second step is analyzing the material collected by the search. The factors limiting the application of BIM are described and classified.

The last step is making suggestions to eliminate these negative factors.

3. Factors limiting the application of BIM

3.1. Summary of factors identified in the literature review

The application of BIM is beneficial to the construction industry and gives a high Return on Investment (ROI), ranging from 634% to 1633% (Azhar *et al.* 2011), from 16% to 1654% through three cases studies (Giel, Issa 2013). Yet, BIM application is much slower than anticipated (Fischer, Kunz 2004). There are many previous studies of the factors that are limiting the application of BIM. Table 2 shows a summary of the factors identified in the literature review.

Table 2. Summary of limitation factors

No.	Factors	Reference	Sum
1	Need to educate professionals about BIM (P1)	Gilligan, Kunz 2007; Eastman <i>et al.</i> 2008; Post 2008; Young <i>et al.</i> 2008; Yan, Damian 2008; Hartmann, Fischer 2008; Arayici <i>et al.</i> 2009, 2011; Sacks, Barak 2010; Singh <i>et al.</i> 2011; Gerber <i>et al.</i> 2011; Nejat <i>et al.</i> 2012; Gledson <i>et al.</i> 2012; Giel, Issa 2013; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Zhang, Gao 2013; Migilinskas <i>et al.</i> 2013; Volk <i>et al.</i> 2014	19
2	Lack of data interoperability (T5)	Bernstein, Pittman 2004; Eastman <i>et al.</i> 2008; Post 2008; McAdam 2010; Azhar <i>et al.</i> 2011; Kim, Anderson 2012; McAuley <i>et al.</i> 2012; Rezgoui <i>et al.</i> 2013; Porwal, Hewage 2013; Aram <i>et al.</i> 2013; Migilinskas <i>et al.</i> 2013; Gupta <i>et al.</i> 2014; Dong <i>et al.</i> 2014; Miettinen, Paavola 2014; Volk <i>et al.</i> 2014; Cao <i>et al.</i> 2015	16

Continue of Table 2

No.	Factors	Reference	Sum
3	Changes in workflows and inappropriate business models (M4)	Bernstein, Pittman 2004; Howell, Batcheler 2004; Méndez 2006; Gilligan, Kunz 2007; Gu <i>et al.</i> 2007; Eastman <i>et al.</i> 2008; Post 2008; Arayici <i>et al.</i> 2009, 2011; Singh <i>et al.</i> 2011; Jensen, Jóhannesson 2012; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Porwal, Hewage 2013; Cao <i>et al.</i> 2015	15
4	No well-developed practical strategies and standards (M2)	Bernstein, Pittman 2004; Eastman <i>et al.</i> 2008; McAdam 2010; Azhar <i>et al.</i> 2011; Singh <i>et al.</i> 2011; Arayici <i>et al.</i> 2011; Jensen, Jóhannesson 2012; Gledson <i>et al.</i> 2012; McAuley <i>et al.</i> 2012; Porwal, Hewage 2013; Migilinskas <i>et al.</i> 2013; Dong <i>et al.</i> 2014; Miettinen, Paavola 2014	13
5	Habitual resistance to change (P2)	Howell, Batcheler 2004; Méndez 2006; Gu <i>et al.</i> 2007; Eastman <i>et al.</i> 2008; Yan, Damian 2008; Singh <i>et al.</i> 2011; Arayici <i>et al.</i> 2011; Jensen Jóhannesson 2012; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Volk <i>et al.</i> 2014	12
6	Cost of specialized software (C2)	Gu <i>et al.</i> 2007; Post 2008; Young <i>et al.</i> 2008; Arayici <i>et al.</i> 2009; Giel, Issa 2011, 2013; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Zhang, Gao 2013; Migilinskas <i>et al.</i> 2013	11
7	Functionality of BIM tools (T1)	Howell, Batcheler 2004; Méndez 2006; Eastman <i>et al.</i> 2008; Post 2008; Hartmann, Fischer 2008; Pihlak <i>et al.</i> 2011; Jensen, Jóhannesson 2012; McAuley <i>et al.</i> 2012; Aram <i>et al.</i> 2013; Miettinen, Paavola 2014; Volk <i>et al.</i> 2014	11
8	Cost in terms of time and training (C1)	Méndez 2006; Arayici <i>et al.</i> 2009; Giel, Issa 2011, 2013; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Zhang, Gao 2013; Migilinskas <i>et al.</i> 2013	10
9	Cost of required hardware upgrades (C3)	Post 2008; Young <i>et al.</i> 2008; Arayici <i>et al.</i> 2009; Giel, Issa 2011, 2013; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Zhang, Gao 2013; Migilinskas <i>et al.</i> 2013	10
10	Contractual environment (L4)	Gilligan, Kunz 2007; Eastman <i>et al.</i> 2008; Hartmann, Fischer 2008; McAdam 2010; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Migilinskas <i>et al.</i> 2013; Miettinen, Paavola 2014; Volk <i>et al.</i> 2014	10
11	Responsibility between stakeholders (L1)	Gilligan, Kunz 2007; Eastman <i>et al.</i> 2008; McAdam 2010; Azhar <i>et al.</i> 2011; Singh <i>et al.</i> 2011; Arayici <i>et al.</i> 2011; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Volk <i>et al.</i> 2014	9
12	Ownership of the BIM data and its copyright (L3)	Gu <i>et al.</i> 2007; Eastman <i>et al.</i> 2008; McAdam 2010; Azhar <i>et al.</i> 2011; Gledson <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Volk <i>et al.</i> 2014	9
13	Fragmented nature of construction industry (M1)	Bernstein, Pittman 2004; Howell, Batcheler 2004; Gu <i>et al.</i> 2007; Singh <i>et al.</i> 2011; Jensen, Jóhannesson 2012; McAuley <i>et al.</i> 2012; Rezgui <i>et al.</i> 2013; Miettinen, Paavola 2014; Volk <i>et al.</i> 2014	9
14	Lack of managers' and owners' awareness and support (M3)	Gilligan, Kunz 2007; Young <i>et al.</i> 2008; Arayici <i>et al.</i> 2011; Nejat <i>et al.</i> 2012; Eadie <i>et al.</i> 2013; Porwal, Hewage 2013; Migilinskas <i>et al.</i> 2013; Cao <i>et al.</i> 2015	8
15	Accessibility of BIM tools (T2)	Méndez 2006; Gilligan, Kunz 2007; Eastman <i>et al.</i> 2008; Gledson <i>et al.</i> 2012; McAuley <i>et al.</i> 2012; Porwal, Hewage 2013; Dong <i>et al.</i> 2014; Volk <i>et al.</i> 2014	8

End of Table 2

No.	Factors	Reference	Sum
16	Safety and reliability of building information (L5)	Méndez 2006; Eastman <i>et al.</i> 2008; Post 2008; McAdam 2010; Rezgui <i>et al.</i> 2013; Porwal, Hewage 2013; Miettinen, Paavola 2014; Volk <i>et al.</i> 2014	8
17	Missing insurance framework for BIM application (L2)	Eastman <i>et al.</i> 2008; Post 2008; Hartmann, Fischer 2008; McAdam 2010; Gledson <i>et al.</i> 2012; Eadie <i>et al.</i> 2013	6
18	Need for sophisticated data management (T4)	Howell, Batcheler 2004; Eastman <i>et al.</i> 2008; Azhar <i>et al.</i> 2011; Ding <i>et al.</i> 2014; Volk <i>et al.</i> 2014; Chen <i>et al.</i> 2015	6
19	Not familiar enough with BIM capabilities (P3)	Gu <i>et al.</i> 2007; Arayici <i>et al.</i> 2009, 2011; Singh <i>et al.</i> 2011; Jensen, Jóhannesson 2012	5
20	Lack of protocols (L6)	Eastman <i>et al.</i> 2008; McAuley <i>et al.</i> 2012; Volk <i>et al.</i> 2014	3
21	Requirement of computable digital design data (T3)	Bernstein, Pittman 2004; Eastman <i>et al.</i> 2008	2
22	Lack of cooperation from other industry partners (M5)	Schlueter, Thesseling 2009	1

3.2. Classification of factors

For the convenience of analysis, all of the factors in the above list are classified into five categories: Technology, Cost, Management, Personnel, and Legal. These categories include 22 sub-factors, which can be seen in Figure 1.

(1) Technological factors

The BIM-based software packages are also called BIM tools. The technological factors refer to BIM tool-related factors limiting the application of BIM, such as imperfect or immature BIM software, a lack of standards and protocols, etc. The restricted capabilities of BIM-based software are the main factor limiting its application in the AEC industry. For instance, lack of scalability, interoperability, and support for remote collaboration, and its unsuitability for the production modeling of cast-in-place (CIP) reinforced-concrete structures are the biggest constraints on the mainstream application of BIM (Post 2008; Barak *et al.* 2009). Interoperability is defined in the IEEE (1990) glossary as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged”. Horizontal fragmentation between participants at a given project phase (e.g., design, construction, or operation), can be caused by the diversity of computer software programs and can contribute to the problem of interoperability (Howard *et al.* 1989). The NIST (National Institute of Standards and Technology) estimates that the total cost of inadequate interoperability is \$15.8 billion a year (Nisbet, Dinesen 2010). Although software users want to improve the interoperability (Young *et al.* 2008), and several inter-

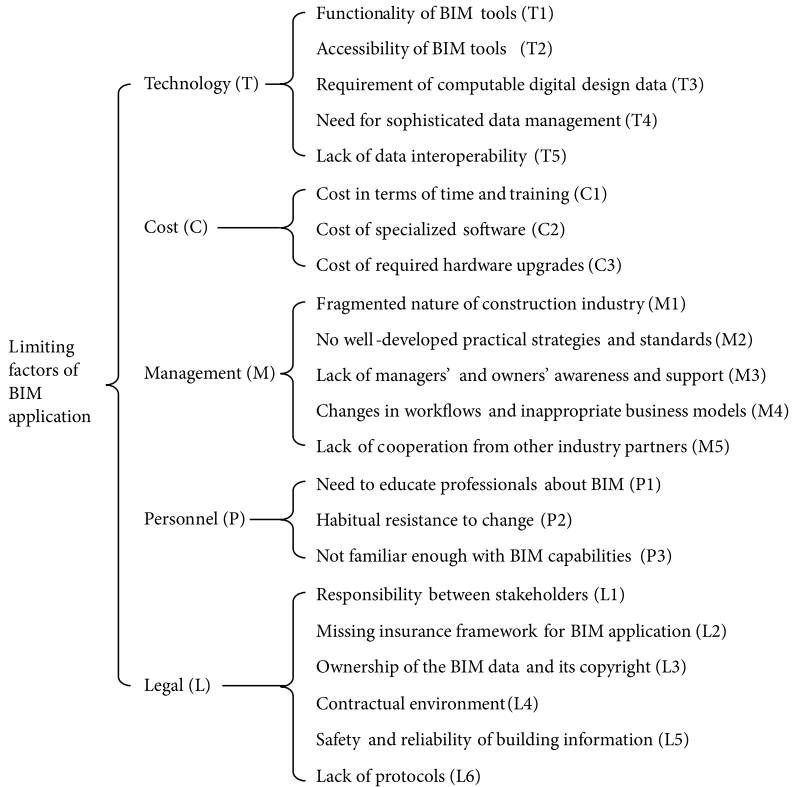


Fig. 1. Categories of factors limiting BIM application

national standards have been developed to address the problems of interoperability, such as STEP and IFCs, there are still a few of shortcomings (Azhar *et al.* 2011; Rezgui *et al.* 2011; McAuley *et al.* 2012). For instance, BIM programs are limited in their static representation of a building and its environment (Rezgui *et al.* 2011). Besides, the study of synchronization data between BIM and on-site real-time building process is a hotspot over years, many methods and technologies, such as laser scanning, radio frequency identification (RFID), augmented reality (AR), geographic information system (GIS), etc., have been applied to acquire and management these sophisticated data for ‘bridging BIM and building (BBB)’ (Chen *et al.* 2015).

(2) Cost factors

These major costs referred to in the literature include buying the BIM-based software and hardware, the software service charges, and training costs, etc. Cost factors refer to the money-related limiting factors in the process of BIM application. Hardin (2009), using an example of one user with a mighty set of tools, estimates the cost of using BIM as \$112,100, including the annual salary of the staff. According to a 2008 McGraw-Hill survey, costs and training issues have been the greatest barriers to the application of BIM (Young *et al.* 2008).

(3) Management factors

Management factors refer to the process and organization-related limiting factors, and include participants' attitudes toward BIM applications, the lack of existing successful cases and management standards for reference, the fragmented nature of the construction industry, the inappropriate business models, and the lack of cooperation from other industry partners. BIM breaks down the traditional boundaries between firms and enables the sharing of project data in a more collaborative environment (Young *et al.* 2008). This means that participants must relocate their roles in the project team and change the workflow of their companies in accordance with the requirements of the BIM application. The changes in everything from file management, to client billing, to deliverables, to coordination meetings are multifarious and complicated, and organizations need time to adapt to these changes (Post 2008). Fragmentation is always an important negative factor affecting the productivity and efficiency of construction projects. Many scholars have studied the effects of fragmentation in the AEC industry and have tried to present some solutions to overcome these effects, such as computer integration (Howard *et al.* 1989; Hwang, Liu 2010). However, Gilligan and Kunz (2007) point out that most participants hesitate to use BIM tools precisely because of the fragmented nature of the construction process, which makes each project unique and not reproducible.

(4) Personnel factors

Personnel factors refer to the professional-related limiting factors. The lack of experienced personnel who are familiar with BIM and have experience using it is another prominent limiting factor. The training and education of large numbers of professionals is necessary for the wider and better application of BIM. Even in design companies, most designers hesitate to use BIM because of the low efficiency, habitual resistance to change, and heavy work demands encountered during the initial period of setting up BIM tools (Zhang 2010).

(5) Legal factors

Legal factors refer to the limiting factors caused by the immaturity of contractual/regulatory environment. Legal and insurance ramifications usually caused by imperfect software can result in lawsuits (Barak *et al.* 2009). Building information models are usually created by different professionals with various software programs and used by different participants. If significant losses occur because of the incorrect use of building information models, claims will become very complicated due to the blurred responsibility. In addition, the regulation of access and the security of building information in building information models (Méndez 2006), ownership and protection of data (McAdam 2010), insurance (Post 2008), protocols (McAuley *et al.* 2012), etc. must also be resolved.

3.3. Analysis of factors

Table 3 shows the frequency with which each of the identified sub-factors appears in the literature review.

Table 3. Statistics of factors limiting the application of BIM

Factors limiting the application of BIM	T					C					M					P			L					
	T1	T2	T3	T4	T5	C1	C2	C3	M1	M2	M3	M4	M5	P1	P2	P3	L1	L2	L3	L4	L5	L6		
Sum	11	8	2	6	16	10	11	10	9	13	8	15	1	19	12	5	9	6	9	10	8	3		
	24					13					25					24			18					

The statistics shown in Table 3 have four implications.

- (1) The most frequently cited limiting factors, from most frequent to least frequent, are management factors (25/39 = 64%), technology factors (24/39 = 62%), personnel factors (24/39 = 62%), legal factors (18/39 = 46%), and cost factors (13/39 = 33%).
- (2) Management factors, technology factors and personnel factors have received the most attention, probably because they are the key barriers limiting the application of BIM. Among personnel factors, the sub-factor “Need to educate BIM professionals” received the most attention. It is the most commonly mentioned sub-factor, discussed in 19 studies. It is clear that the lack of BIM professionals is an issue of wide concern, and training large numbers of professionals is an urgent prerequisite for the expansion of BIM. Among technology factors, “lack of data interoperability” is the most commonly mentioned sub-factor and discussed in 16 studies. Among management factors, the sub-factor “changes in workflow and inappropriate business models” has received the most attention and is discussed in 15 studies.
- (3) Legal factors have received the fourth most attention. Among legal factors, the sub-factors “contractual environment”, “responsibility between stakeholders” and “ownership of the BIM data and its copyright” have received the most attention and are discussed in 10, 9, 9 studies separately.
- (4) Although cost is an important factor in the implementation of BIM, few scholars have studied it deeply for the problems associated with cost are very specific and can be easily resolved. Among cost factors, the sub-factor “cost of specialized software” has received the most attention and is discussed in 11 studies.
- (5) Among 39 studies, 2 studies were published in 2004, 1 study in 2006, 2 studies in 2007, 6 studies in 2008, 2 studies in 2009, 2 studies in 2010, 5 studies in 2011, 5 studies in 2012, 7 studies in 2013, 5 studies in 2014, and 2 studies in 2015. Studies of the barriers hindering BIM application have become more common in the last years. This means that the ways in which these barriers have blocked the practical application of BIM are now more obvious, as is the urgent need for effective solutions. It also illustrates that more scholars and professionals are being drawn to the study of BIM.

Conclusions and suggestions

BIM technology has developed very quickly over the last decade. It has been widely used in many huge construction projects, which have proven that great benefits can be achieved by applying BIM. However, there are many barriers limiting the further development and

application of BIM. Our critical analysis of the literature has led to the development of a general understanding of the factors limiting BIM application. There are five categories of limitations: (1) Technology, (2) Cost, (3) Management, (4) Personnel, and (5) Legal. The most commonly cited categories are Management, Technology and Personnel. Specifically, industry insiders believe that the lack of professionals, lack of data interoperability and changes in workflow are the key barriers to the expansion of BIM.

To facilitate further development and wider application of BIM, we make the following four suggestions according to the five limiting factors identified before.

- (1) Concerning the technique limiting factors, researchers and the providers of BIM tools should speed up the development of mature data exchange standards, and focus on creating seamless interoperability among participants with different BIM-tools. IFC is regarded as the best option for achieving interoperability, but some other standards and methods, such as IDM (Information Delivery Manuals), MVD (Model View Definitions) and IFD (International Framework for Dictionaries), also play a significant role to make BIM interoperability a reality (Santos 2009; Volk *et al.* 2014). Providers of BIM tools should make their products more compatible, user-friendly, and interoperable.
- (2) Concerning the cost limiting factors, we think cost should not be key hindrances to BIM implementation, as cost for staff training, software and hardware can be compensated by the great long-term benefits of BIM (Azhar *et al.* 2011; Jernigan 2007). Furthermore, BIM users (owners, designers, construction companies, consultants, etc.) should adopt BIM as soon as possible, because BIM is the future of the construction industry and in all probability companies that do not adopt it will be eliminated.
- (3) Concerning the management limiting factors, first of all, for workflow must be changed to adapt to the new advanced technologies, the problems caused by changes in workflow should be treated with actively. Secondly, researchers should study deeply how BIM can be used in cost management, schedule management, safety management on construction projects, etc., and develop guidelines and standards or strategies for BIM. Thirdly, as far as possible, construction management should adopt IPD (Integrated Project Delivery). As it reduces the effect of fragmentation, the IPD method is a much better construction project delivery method than the traditional design-bid-build delivery method, and there are great benefits to couple BIM to IPD (Ilozor, Kelly 2012). Finally, as the ultimate aim of a construction project is to meet the owner's requirements, owner motivation is the most important factor in BIM application (Nisbet, Dinesen 2010).
- (4) Concerning the personnel limiting factors, stakeholders in the construction industry and universities should provide more BIM courses so that students can be familiar with BIM before they start to work. More training is necessary to expand the application of BIM in the construction industry, as research shows that users achieve more positive results from BIM, as they develop higher levels of expertise (Young *et al.* 2008).
- (5) Concerning the legal limiting factors, at the macroscopic level of industry management, joint efforts by governments, industry associations, and corporations are needed to promulgate better laws, regulations, and contract systems for BIM application. In particular, governments should promote BIM in entire industries, as does the American government organization (General Services Administration, GSA) (Eastman *et al.* 2008).

Different countries, different time, or even different practical construction projects have different limiting factors, and it is the limitation of the study that didn't distinguish these differences. Concerning the methodological approach, the second search condition does not adopt the negative form of positive outcomes of BIM uses, so some literature may be missed. Furthermore, correlations between limiting factors are too complex so that they have not been studied in this paper. The following research direction is: using the research results of this paper and adopting the questionnaire method, the limiting factors in different applying background and the correlations between limiting factors will be gotten, and this will bring great benefits to practical project.

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