BIM Acceptance Model in Construction Organizations

Seulki Lee[1]; Jungho Yu[2]; and David Jeong[3]

Abstract: Substantial research has been performed on the data standards and exchanges in the Architectural, Engineering, Construction/Facility Management (AEC/FM) industry over the past several years. The growing popularity of building information modeling (BIM) technology is based heavily upon the perception that it can facilitate the sharing and reuse of information during a project life cycle. Although many researchers and practitioners are in agreement about the potential applicability and benefit of BIM in construction, it is still unclear why BIM is adopted, and what factors enhance implementation of BIM. Thus, BIM acceptance and use remains a central concern of BIM research and practice. Therefore, we propose an acceptance model for BIM in construction organizations using structural equation modeling (SEM). The key components, including the BIM acceptance model (BAM), are identified through a literature review about technology acceptance-behavior related theories, and was then consolidated by interviews and pilot studies with professionals in the construction industry. Based on the components, a questionnaire was designed and sent out to workers in construction organizations (such as contractors, architects, construction managers, and engineers) in South Korea. A total of 114 completed questionnaires were retrieved. We used SEM for hypothesis testing. The validated BAM can serve as a foundation for positioning and comparing BIM acceptance research and provides users with a framework for evaluating BIM acceptance. **DOI: 10.1061/(ASCE)ME.1943-5479.0000252.** *© 2014 American Society of Civil Engineers.*

Author keywords: Building information modeling (BIM); Technology acceptance model (TAM); Structural equation modeling (SEM).

Introduction

According to a 2004 National Institute of Standards and Technology (NIST) report (NIST 2004), the capital facilities construction industry wastes $15.8 billion annually due to interoperability inefficiencies. These inefficiencies include the reentry and recreation of information and data, and a duplication of business functions (Newton 1995). Using building information modeling (BIM), these inefficiencies can be solved (Mendez 2006). BIM is "a new approach to design, construction, and facilities management, in which a digital representation of the building process [is used] to facilitate the exchange and interoperability of information in digital format" (Eastman et al. 2008). In the construction industry, there is a growing interest in the use of BIM for coordinated, consistent, and computable building information/knowledge management from design to construction to maintenance and the operation stages of a building's life cycle.

Although many researchers and practitioners are in agreement about BIM's potential applicability and benefits in construction, it is still unclear how BIM could be used, and what the benefits are to implementing BIM. Thus, BIM adoption and use remains a central concern of BIM research and practice. One of the key measures of implementation success is achieving the intended level of usage of information technology (IT). IT usage is a reflection of acceptance of the technology by users (Venkatesh 1999). There is a growing body of academic research examining the determinants of IT acceptance and utilization among users (Patrick and Paul 2002; Taylor and Todd 1995). In particular, the technology acceptance model (TAM) (Davis 1989) has served as a basis for research in dealing with behavior intentions and usage of IT.

Previous research argued in favor of investigating antecedent variables that can explain the core TAM variables and extend TAM in a way that enhances our ability to better understand the acceptance and usage of existing and new IT. Factors contributing to the acceptance of IT are likely to vary with the technology, target users, and context (Moon and Kim 2001). Most of the prior studies were carried out in traditional and relatively simple, but important environments, such as for personal computing, e-mail systems, word processing, and spreadsheet software (Hong et al. 2002). Technology assessment theories provide a sound theoretical base for examining factors influencing the use of BIM for construction organizations. Constructs for use in this research are based on those discussed in these theories. These constructs were selectively used based on their relevance in the BIM context as evidenced by previous surveys and case studies on the use of BIM.

The main purpose of this research is to develop and validate the BIM acceptance model based on technology acceptance behavior-related theories. This research is structured as follows. First, TAM developed by other researchers is reviewed and then BIM acceptance in construction is defined. Second, based on a literature review, each measured item of the BIM acceptance model and a comprehensive set of hypotheses are proposed. Third, the methods and results of a survey are presented. Finally, theoretical and managerial implications and directions for future research are discussed. The data used to test the research model were obtained from a sample of experienced users (contractors, architects, and engineers) of BIM. To generalize the results, the respondents were spread across construction sites. Using *AMOS* 20.0 (AMOS 20.0 2011), structural equation modeling (SEM) was employed for hypothesis testing. A two-phased approach was adopted, based on the work of Anderson and Gerbing (1988). First, a measurement model was estimated using confirmatory factor analysis (CFA) to test the overall fit of the model,

[1]Ph.D. Student, Dept. of Architecture Engineering, Kwangwoon Univ., KwangWoon-ro 20, Nowon-gu, Seoul, South Korea.

[2]Associate Professor, Dept. of Architecture Engineering, Kwangwoon Univ., KwangWoon-ro 20, Nowon-gu, Seoul, South Korea (corresponding author). E-mail: myazure@kw.ac.kr

[3]Associate Professor, Dept. of Civil, Construction, and Environmental Engineering, Iowa State Univ., 326 Town Engineering, Ames, IA 50011.

Note. This manuscript was submitted on March 12, 2013; approved on August 8, 2013; published online on August 10, 2013. Discussion period open until September 28, 2014; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, © ASCE, ISSN 0742-597X/04014048(13)/$25.00.

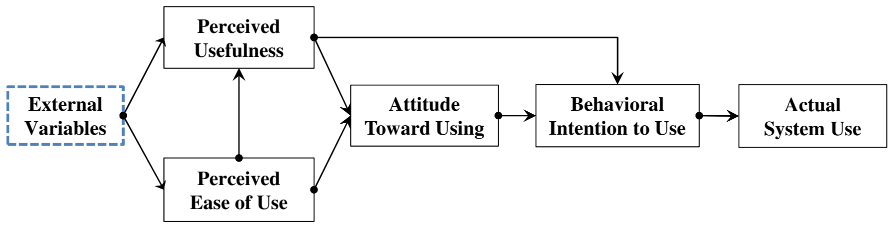

Fig. 1. Technology acceptance model (TAM)

as well as its validity and reliability. Second, the hypotheses were tested between constructs using the structural model.

Literature Review

Acceptance Behavior-Related Theories

Introduced by Davis (1989), TAM is an adaptation of the theory of reasoned action (TRA) and the theory of planned behavior (TPB) specifically tailored for modeling user acceptance of information systems. The goal of TAM is to provide an explanation of the determinants of computer acceptance that is capable of explaining user behavior across a broad range of end-user computing technologies and user populations, while at the same time being both parsimonious and theoretically justified. In this model, perceived usefulness and perceived ease of use are of primary relevance for IS acceptance behavior. TAM proposes that external variables indirectly affect attitude toward use, which ultimately leads to actual system use by influencing perceived usefulness and perceived ease of use (Fig. 1).

TAM assumes that an individual's behavioral intention to use a system is determined by two beliefs: perceived usefulness, defined as the extent to which a person believes that using the system will enhance his or her job performance, and perceived ease of use, defined as the extent to which a person believes that using the system will be free of effort. TAM assumes that the effects of external variables (e.g., system characteristics, development process, training) on intention to use are mediated by perceived usefulness and perceived ease of use.

Barki and Hartwick (2001) found that subjective norms have a significant impact on intention in a mandatory system use, but not in voluntary settings. Thus, the updated TAM, also called TAM2, extended the original TAM by including subjective norms as an additional predictor of intention in the case of mandatory system use. The causal relationships and elements of TAM2 are described in Fig. 2 (Venkatesh and Davis 2000). Further research on TAM led to the development of TAM3 (Venkatesh and Bala 2008) (Fig. 3).

TAM, however, has limited application when extended beyond the workplace because its fundamental constructs do not fully reflect a variety of the user task environments and constraints. Paul et al. (2003) suggested that TAM is a useful model but needs to be integrated into a broader model that includes variables related to both human and social factors. To take these limitations into account, the theory of planned behavior (TPB) (Ajzen 1985) incorporates subjective norms (SN) and perceived behaviors control (PBC) as direct determinants of behavior (BI) (Fig. 4). TPB asserts that BI is jointly determined by one's attitude, which reflects positive feelings toward performing a behavior; SNs reflect perceptions that other people desire the individual to perform in a particular way; and PBC reflects internal and external constraints on the performance the action (Fu et al. 2006).

As another acceptance model, the task-technology fit model (TTF) matches the capabilities of a technology to the demands of the task, as depicted in Fig. 5. The availability of IT to support a task is expressed by the formal construct known as TTF, which implies matching the capabilities of the technology to the demands of the task (Goodhue and Thompson 1995). TTF posits that IT will be used if, and only if, the functions available to the user support (i.e., fit) the activities of the user. Rational, experienced users will

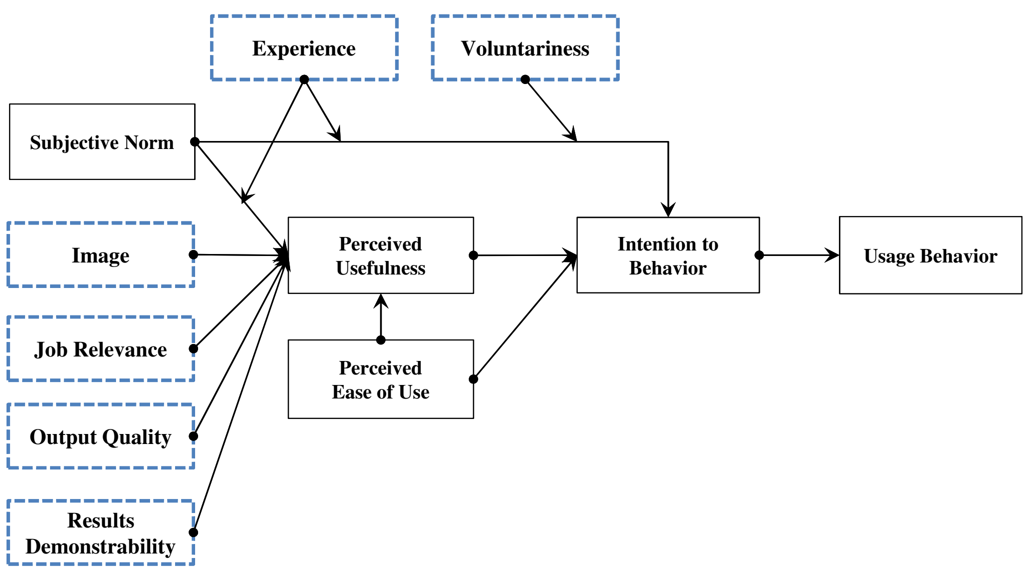

Fig. 2. Technology acceptance model 2 (TAM2)

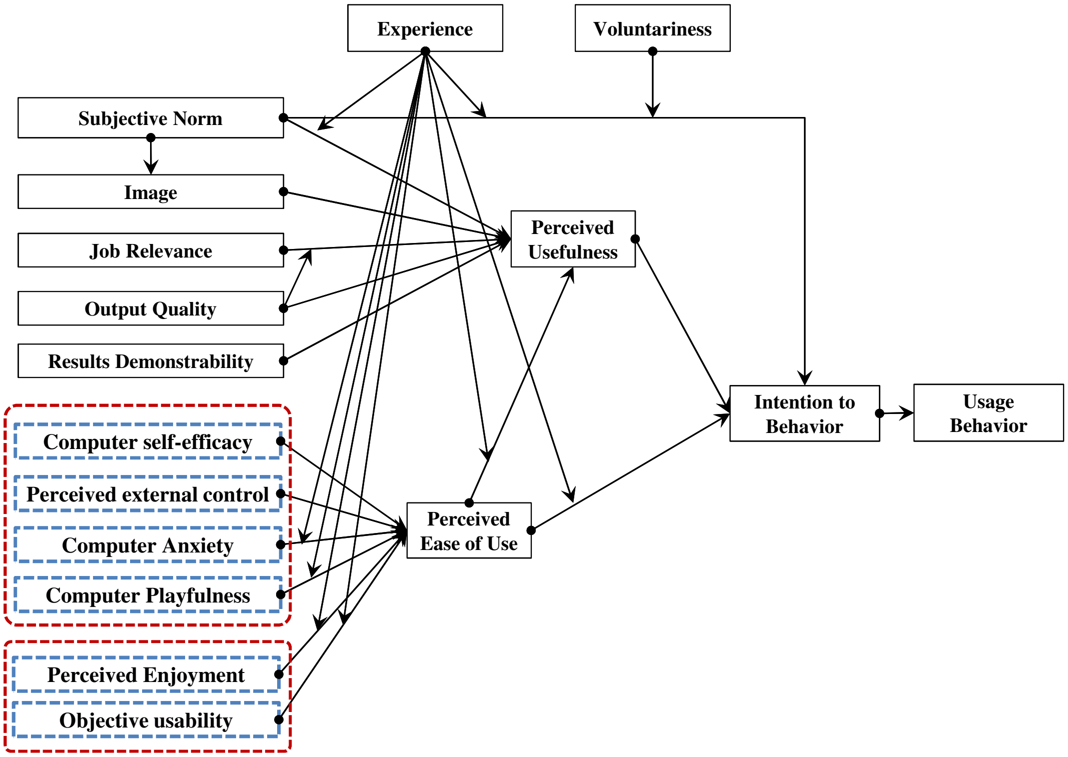

Fig. 3. Technology acceptance model 3 (TAM3)

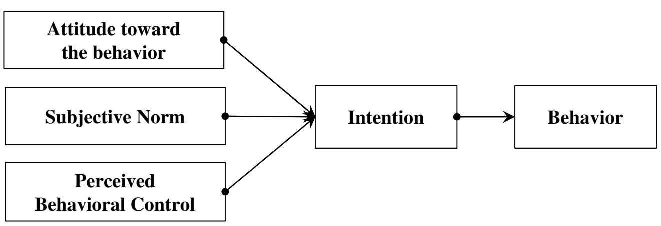

Fig. 4. Theory of planned behavior (TPB)

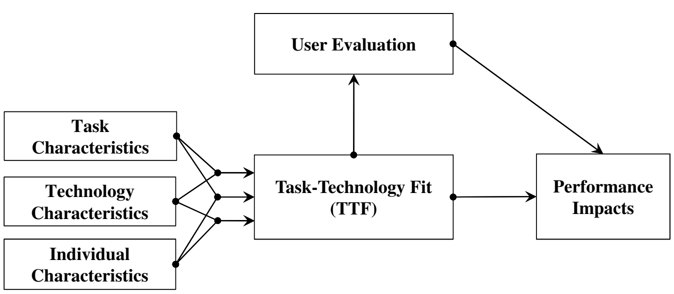

Fig. 5. Task-technology fit model (TTF)

choose those tools and methods that enable them to complete the task with the greatest net benefit. IT that does not offer sufficient advantage will not be used. TTF models have four key constructs: the first two are task characteristics and technology characteristics, which together affect the third construct, technology fit, which in turn affects the final construct outcome variable, either performance or utilization.

One of the key measures of implementation success is achieving the intended level of IT usage. This is because the factors that affect usage can be used to define a mechanism for achieving the acceptance of BIM in construction organizations. In this respect, the BIM acceptance model is significant in relevant research fields for several reasons. First, the BIM acceptance model is used to provide a generalized framework that explains BIM acceptance-related behavior. Second, based on proven technology acceptance-related theories, a systematic combination of individual criteria that correspond to the BIM acceptance category can facilitate the establishment of a comprehensive scale for measuring the readiness of BIM acceptance. Third, technology acceptance models can be used by researchers to explore the causal relationship between technology acceptance and its drivers and can be used as a mechanism by end-users to determine whether the expected technology acceptance has been achieved. Fourth, numerous studies that attempted to empirically verify technology acceptance models firmly support the relationship of the criteria to acceptance and help to ascertain the causal structure in models.

One of the most widely applied technology acceptance models is the one proposed by Davis (1989). Davis suggested several variables of technology acceptance; since then, a significant amount of research in many fields has been conducted to verify, extend, and improve the model. In the construction field, research using technology acceptance models has recently been carried out to examine a technology acceptance model for enterprise resource planning (ERP) in construction (Chung et al. 2008, 2009) and the usability analysis of a PMIS (Nam et al. 2008). Nonetheless, research on acceptance models for BIM that reflect the opinions of construction project stakeholders is scarce in South Korea; accordingly, the mechanisms for acceptance achievement or BIM acceptance have yet to be defined.

BIM Acceptance in the AEC Industry

BIM identifies the properties of each building object, and recognizes the relationships among these properties. It allows changes to be implemented instantly to each building element, thus supporting quicker, cheaper, and improved building facilities throughout the entire production process. When BIM is used, various types of information provided by the architecture, engineering, and construction (AEC) industry can be utilized more efficiently. Like many countries, South Korea has been trying to establish the application of BIM through various approaches. The tasks in the AEC industry that can utilize BIM are as follows:

- 3D visualization (architecture/structure/MEP);
- Clash detection;
- Feasibility studies;
- Model-based quantity take-off and estimation;
- Visualized scheduling (4D) management;
- Environmental analysis or Leadership in Energy & Environmental Design (LEED) certification (energy efficiency/sunshine/CO_2 emission analysis);
- Creation of shop drawings and schedule management for installation of rebar/steel frame/curtain wall;
- Visualized constructability review (material lifting operation planning/temporary resources installation);
- Visual and geospatial coordination for construction of atypical shapes; and
- Creation of as-built model for facility management.

As shown, the advantages of BIM in the construction industry include support for graphic elements and a data management environment. BIM not only provides information related to quantity, cost, schedule, and material inventory to aid prompt decision making, but also allows data analysis that takes into consideration the specific structure and environment. Despite these advantages, the application of BIM in the construction industry has been slow due to the following obstacles (Choi 2010; Lee et al. 2007, 2009; SmartMarket Report 2012):

- Unclear and invalidated benefits of BIM in ongoing practices;
- Lack of familiarity with adopting this new technology;
- Lack of supporting education and training for use of BIM;
- Lack of supporting resources (software, hardware) to use BIM tools;
- Lack of effective collaboration between project stakeholders for modeling and model utilization;
- Unclear roles and responsibilities for loading data into a model or databases and maintaining the model; and
- Lack of sufficient legal framework for integrating owners' view in design and construction.

Many of the recent BIM-related studies emphasize the development of an application technology based on BIM, and the need to utilize BIM through case studies (Park et al. 2011; An et al. 2009; Froese and Yu 1999; Tulke et al. 2008). However, there are few studies that suggest BIM utilization methods or that deduce the impeding factors for BIM utilization (Choi 2010; Lee et al. 2007, 2009; SmartMarket Report 2012). Moreover, although influential factors are systematically listed, many of them focus only on the technological aspects of BIM improvement methods. Thus, research on the correlation between influential factors and BIM utilization is insufficient.

As discussed previously, BIM allows integrated information management through compatibility and sharing of information in all stages of the life cycle. It is a technology that establishes a cooperation system among the different sectors, and allows for smooth communication among those sectors. Thus, it is different from other information technologies that only consider an individual's perspective when determining the status of acceptance of an information technology. Completed acceptance of BIM technology can be achieved not only through the acceptance by an individual using BIM tools for his tasks, but also through the acceptance of a group for compatibility and sharing of information throughout the project life cycle. Thus, the acceptance of BIM is possible when an individual is willing to utilize the information and tools in BIM for their own tasks and an affiliated organization is also willing to establish a cooperation system that utilizes BIM.

The Proposed BIM Acceptance Model

Overview of Proposed Model

Despite agreement about the potential applicability and benefits of BIM in construction, it is still unclear how BIM could be used, and what the benefits are to implementing BIM. Thus, BIM acceptance remains a central concern of BIM research and practice. Therefore, our objective is to understand the mechanism of BIM acceptance based on empirically tested and proven research models such as TAM-related theories (Davis 1989; Venkatesh and Davis 2000; Venkatesh and Bala 2008; Ajzen 1985; Goodhue and Thompson 1995), the IS success model (DeLone and McLean 1992, 2003; Seddon and Kiew 1996; Seddon 1997; Pitt et al. 1995; Myers et al. 1997), and the motivation model (Deci 1975; Deci and Ryan 1985, 1987).

The proposed model provides the rationale for the variables based on the theoretical background on TAM, and the motivation model incorporates additional variables based on literature regarding BIM use. Based on the preceding concepts, a research model for BIM acceptance is proposed. The model consists of (1) IS success model-related factors (technology quality), (2) motivation model-related factors (organizational competency, personal competency, and behavior control) as the external variable for BIM acceptance, and (3) TAM-related factors (perceived ease of use, perceived individual usefulness, and perceived organizational usefulness) as mediation variables for BIM acceptance and intention to accept BIM (individual intention of BIM acceptance and organizational intention of BIM acceptance).

External Variables for BIM Acceptance

TAM assumes that the effects of external variables (e.g., system characteristics, development process, training) on intention to use are mediated by perceived usefulness and perceived ease of use. From the literature review, there is no clear pattern with respect to the choice of the external variables considered. The selection of external variables not only contributes to theory development, but also leads to improved technology acceptance. Actually, external variables provide a better understanding of what influences perceived usefulness and perceived ease of use, and the presence of external variables guides the actions required to influence greater use. We suggest external variables for BIM acceptance as the key factors affecting the acceptance of BIM in construction organizations.

In this research, a total of 28 key factors of BIM acceptance were initially selected from the aforementioned TAM and other various researches. The factors were classified into nine categories: compatibility, output quality, collective efficacy, organizational innovativeness, self-efficacy, personal innovativeness, top management support, internal pressure, and external pressure. Then, a questionnaire was developed to collect opinions from experienced users regarding BIM acceptance. The content validity of the 31 items on the questionnaire was tested through face-to-face interviews with three experts who have more than 5 years of experience each and know that BIM can be used for their tasks. The experts were also asked to review the questionnaire for redundancy and accuracy. After the interview, the number of factors was reduced to 27.

The next step involved testing construct validity using exploratory factor analysis (EFA), which is generally used to identify a relatively small number of factor groups that can be used to represent relationships among sets of many interrelated variables. In the EFA, a total of 114 user responses collected by the developed questionnaire were used. In general, two main issues need to be considered in determining whether a data set is suitable for factor analysis: the sample size and the strength of the relationship among the variables (Pallant 2001). Hair et al. (1998) argued that an appropriate sample size should be at least 4–5 times the number of variables. In this research, the sample size was five times larger than the number of variables, which was sufficient for factor analysis. On the other hand, in terms of the strength of the relationships among the variables, the Kaiser-Myer-Olkin (KMO) test (Kaiser 1970) and Bartlett's test of sphericity (Bartlett 1954) were recommended. The KMO index is a measure of sampling adequacy, and the sphericity statistic tests measure whether the correlations among variables are too low for the factor model to be appropriate. For the KMO index of sampling adequacy, a value above 0.6 is required for good factor analysis; our value of 0.849 was satisfactory. For Bartlett's test of sphericity, a significant value of less than 0.05 ($p < 0.05$) is required; ours was satisfactory. Therefore, the results of these tests confirm that the data were appropriate for factor analysis. The criteria used in the EFA were "eigenvalues greater than 1" and "factor loadings greater than 0.5" (Norusis 1992; Li et al. 2005; Aksorn and Hadikusumo 2008). Eigenvalues determine the number of factors. The sum of the squared loadings of the variables on a factor is known as the eigenvalue of the factor. Dividing the eigenvalue by the number of variables gives the proportion of variance explained by the factor. The higher the eigenvalue is, the higher the proportion of variance explained by the factor. Thus, it is possible to set a criterion eigenvalue for the acceptance of a factor as being important enough to consider. By convention, the usual criterion value is 1. In this research, we used principal component analysis with varimax rotation as the method for data analysis. The factor analysis identified three factor groups: organizational competency (nine items), technology quality (seven items), personal competency (six items), and behavior control (five items).

Finally, the reliability of the factors was tested using Cronbach's coefficient alpha value. The Cronbach's α value that is considered acceptable is 0.6 (Nunnalyy 1978). The test results showed that Cronbach's α ranged from 0.915 to 0.927, thus confirming that the measures used in the assessment were statistically reliable.

Organizational Competency

Collective efficacy: This concept refers to the organizational dimension to inquire about efficacy beliefs in organizations. Inquiry into collective efficacy beliefs emphasizes that teachers have both self-referent efficacy perceptions and also beliefs about the conjoint capability of users. Such group referent perceptions reflect an emergent organizational property known as perceived collective efficacy (Goddard et al. 2000; Hoy et al. 2002).

Organizational innovativeness: This term was defined as the willingness of an organization to try out any new information technology. To successfully accept BIM, effective collaboration and clear role sharing for modeling among construction organizations are necessary. All construction organizations must comply with standardized policies and procedures for modeling. Therefore, personal innovativeness as well as organizational innovativeness should be considered.

Top management support: Top management support has been extensively recognized as an important variable in technology implementation studies (Gilligan and Kunz 2007). The decision by an organization to adopt BIM may be risky unless there is a firm commitment from top management. Gilligan and Kunz (2007) found that top management commitment was one of the major success factors for adopting BIM technologies. It is anticipated that firms that have significant top management support to accept BIM are more likely to use BIM.

Technology Quality

Compatibility: Compatibility, defined as the degree to which the technology fits the potential adopter's previous experience, work practice, system use and needs, has been identified as an essential factor for innovation adoption (Moore and Benbasat 1991). Considerable prior research has reported a significant effect of compatibility on the user technology acceptance decision.

Output quality: In the construction industry, there is a growing interest in the use of BIM in construction for coordinated, consistent, and computable building information/knowledge management. The information collected through a BIM process and stored in a BIM-compliant database could be beneficial for a variety of construction practices. Therefore, the output quality of BIM is measured by capability of search, accessibility, and trust of information.

Personal Competency

Self-efficacy: The concept of self-efficacy originates from social cognitive theory (Bandura 1977). It refers to the conviction that one can successfully execute the behavior required to produce the outcome. Self-efficacy is defined as perceived behavioral control, which means the perception of the ease or difficulty of the particular behavior. It is linked to control beliefs, which refer to beliefs about the presence of factors that may facilitate or impede performance of the behavior.

Personal innovativeness: Personal innovativeness is defined as the willingness of an individual to try out any new information technology. According to Agarwal and Prasad (1997), personal innovativeness helps identify individuals who are likely to adopt IT innovations earlier than others. Learning a person's individual innovativeness would help us to further understand how perceptions are formed and the subsequent role they play in the formation of individual behavior.

Behavior Control

Internal pressure: Internal pressure means the impact of superiors and colleagues within the organization. Venkatesh and Davis (2000) found that internal pressure had a significant impact on intention in a mandatory system. In mandatory settings, social influence appears to be important only in the early stages of individual experience with the technology, with its role eroding over time and eventually becoming insignificant with sustained usage.

External pressure: External pressure involves the influences arising from several sources within the competitive environment surrounding the organization. Enacted user power measures the strength of the influence strategy used to exercise that potential power. External variables for BIM acceptance are shown in Table 1.

Internal Variables for BIM Acceptance

Perceived Ease of Use

Previous research suggests *ease of use* as one of the key determinants for successful acceptance of IT. Perceived ease of use refers to the degree to which a person believes that using a particular system would be free of effort. This follows from the definition of ease: freedom from difficulty or great effort. Davis (1989) asserted that a technology tharwas observed to be easier to use than another was more likely to be accepted. These findings lead to the hypothesis that there is a positive relationship between ease of use and intention of acceptance.

Table 1. Assessment Items of External Variables for BIM Acceptance

Variables	Assessment items
Organizational competency	
Collective efficacy	My organization does not have any resistance to using BIM
	My organization is familiar to BIM tools
	My organization understands the benefits of using BIM
Organizational innovativeness	My organization does not have psychological resistance to using new IT
	My organization has technical capability of using new information technology
	My organization is aggressive pushing to use new information technology
Top management support	My organization supports enough resources (hardware and software) for BIM utilization
	My organization provides proper education/training for BIM utilization
	My organization provides incentives if we adopt or utilize BIM
Technology quality	
Compatibility	BIM tools that I use are easy for data input and output
	Screen interface of BIM tools that I use are easily built so that everyone can use easily
	BIM tools that I use are stable when using
Output quality	BIM utilization improves information accessibility
	Information acquired by using BIM is accurate and detailed
	Enough information can be gathered using BIM
	Information acquired by using BIM can be used throughout the course of the project
Personal competency	
Self-efficacy	I do not have any resistance to using BIM
	I am familiar with BIM tools
	I understand the benefits of using BIM
Personal innovativeness	I do not have psychological resistance to using a new information technology
	I have technical capability of using a new information technology
	I am aggressive about using a new information technology
Behavior control	
Internal pressure	My organization forces us to use BIM by setting up policies and regulations
	I am required to use BIM by superiors and colleagues
External pressure	We are required to adopt BIM by project delivery or contract method
	We are required to adopt BIM by cooperative companies and cooperative relations
	We are required to adopt BIM to satisfy owner's requirements

Therefore, it is assumed that the belief that BIM is easy to use will be directly related to the perceived usefulness, consensus on appropriation, and the intention to accept BIM. There were a total of three questions to assess the degree of perceived ease of use: ease of learning how to cooperate with BIM, ease of exchanging information among stakeholders, and ease of using the guidelines for collaboration.

Perceived Usefulness

User perception of usefulness has been considered an important factor in technology acceptance. Davis (1989) defined user perception of usefulness as the degree to which a person believes that using a particular system would enhance his or her job performance. This follows from the definition of useful: capable of being used advantageously. Previous research found that it was strongly correlated with acceptance intention.

The acceptance of BIM is possible when an individual is willing to utilize the information and tools in BIM for one's tasks and when one's affiliated organization is willing to establish a cooperation system that utilizes BIM. Therefore, the measurement items for perceived usefulness can be divided largely into individual and organizational recognition that BIM utilization improves working ability and productivity.

Consensus on Appropriation

Consensus on appropriation is defined as the extent to which individuals agree on how to jointly use an advanced information technologies (AIT) intervention (Gerardine and Marshall 1992; Marshall and Gerardine 1994). If consensus on appropriation is not reached, effective coordination of users' efforts may be difficult, which would likely lead to unfavorable outcomes. In many environments, users are not left solely to their own devices to resolve uncertainty about how to appropriate the AIT.

High consensus on appropriation elicits repetitive use of IT established by a single user; through such methods, it allows adaptation or reproduction of the structure. A high level of consensus on the use of IT indicates that the cooperation system among group constituents is well established. Such cooperative acts related to IT use allow constituents to gain a sense of intimacy and unity, which will help them to gain a more active and cooperative attitude toward achieving the group's goals. A consensus on appropriation reflects the opinion of Lee (1994), who views IT not as a fixed artifact but as a kind of social feature. Consensus on appropriation has as significant impact on the acceptance of Internet-based systems, such as e-mail, group decision support, and enterprise resources planning (ERP), where communication among users is the main function. Thus, consensus on appropriation can also have a large influence on the acceptance of BIM, where the main function is the establishment of a cooperation system and support for a communication system among different sectors. Internal variables for BIM acceptance are shown in Table 2.

Intention to Accept BIM

Behavioral intention is a measure of the strength of one's intention to perform a specified behavior (Fishbein and Ajzen 1975). Many researchers expect behavioral intention to have a significant positive influence on technology acceptance. User acceptance has been incorporated as a dependent variable in the majority of IT implementation research (Saga and Zmud 1994). Davis et al. (1989) suggested that user acceptance is a prerequisite of system use. Regardless of the view adopted, it is clear that user acceptance is

Table 2. Assessment Items of Mediation Variables for BIM Acceptance

Variables	Assessment items
Perceived usefulness	Interoperability among stakeholders is improved when BIM is used
	Using BIM allows comprehensive management of life-cycle information (design-construction-O&M)
	Decision-making time is reduced when BIM is used
	BIM utilization may expand the range of collaboration with other organizations
	Work task-handling time can be reduced when using BIM
	Task accuracy can be improved when utilizing BIM
	Fast response is possible on any changes when using BIM
Perceived ease of use	It is easy to learn how to cooperate with BIM
	If we adopt BIM, it is easy to exchange information among stakeholders
	The guideline for collaboration with BIM is defined so that we could follow easily
Consensus on appropriation	The members of the organization have conformity on the tasks that apply BIM, which is set by the organization
	The members of the organization have conformity on how to apply BIM (such as related work guideline s and rules), which is set by the organization

critical to successful implementation. In this research, BIM acceptance is considered as a dependent variable.

To complete acceptance of BIM technology, individuals must use BIM tools for their tasks, and a group must use BIM for compatibility and sharing of information throughout the project life cycle. Therefore, the measurement items for individual intention to accept BIM are willingness to utilize BIM tools and information to fulfill his tasks, willingness to spend time to utilize BIM, and willingness to recommend BIM to coworkers or other entities in a cooperative relationship. The measurement items for organizational intention to accept BIM are willingness to encourage the use of BIM among group constituents, willingness to recommend the use of BIM to other organizations in cooperative relationships, and willingness to develop BIM application technology (Table 3).

Proposed Model and Research Hypotheses

We propose a research model for empirical analysis on the intention to accept BIM based on the previous literature review of the TAM

Table 3. Assessment Items of Individual and Organizational Intention to Accept BIM

Variables	Assessment items
Individual intention of BIM acceptance	I have an intention to use BIM for performing my task
	I have an intention to recommend BIM to others
	I have an intention to take time to learn how to use BIM
Organizational intention of BIM acceptance	My organization encourages members of organization to use BIM technology
	My organization is active in working on projects using BIM
	My organization has an intention to recommend BIM to other organizations that we have a cooperative relationship with
	My organization has an intention to participate in adopting and developing BIM application technology

(Fig. 6). The proposed model includes 46 observed indicators describing 9 latent constructs (assessment items and factors): organization competency, technology quality, personal competency, behavior control, perceived ease of use, perceived usefulness, consensus on appropriation, individual intention to accept BIM, and organizational intention to accept BIM.

The hypotheses are established based on the proposed research model (Table 4). The basis for the established hypotheses was presented in the preceding sections.

Using *AMOS* 20.0, we employed SEM for hypotheses testing. A two-phased approach was used based on the work of Anderson and Gerbing (1988). First, the measurement model was estimated using CFA to test the overall fit of the model, as well as its validity and reliability. Second, the hypotheses were tested between constructs using the structural model.

Model Validation

Data Collection

This case study aimed to propose a BIM acceptance model that is widely used in the Korean construction industry. The data used to test the research model were obtained from a sample of experienced BIM users (designer, CMs, contractors, engineers). The questionnaire was sent by e-mail through the project directors of each organization. The survey was conducted between April 11 and June 12, 2012; a total of 114 responses were received, all of which were valid and used for the analysis. Among the 114 respondents, 36 were from designer organizations, 30 from construction management organizations, 33 from constructor organizations, and 15 from engineer organizations. Each item was measured on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree." The descriptive statistics relating to the respondents' characteristics are shown in Table 5.

Measurement Model

Common model fit measures were used to assess the model's overall goodness of fit: the ratio of X^2 to degree of freedom (df), root-mean square residual (RMR), parsimonious goodness of fit index (PGFI), the Tucker-Lewis index (TLI), comparative fit index (CFI), and root-mean square error of approximation (RMSEA) (Baumgartner and Homburg 1996). As shown in Table 6, all of the model-fit indices refer to their respective common acceptance levels as suggested by previous research (Hair et al. 1998; Jiang et al. 2002; Wang and Liao 2008).

In Table 6, the model-fit indices of the proposed model and the acceptance level are compared. More than half the model-fit indices meet the acceptance level. RMR, TLI, and CFI are close to the acceptance level. Thus, the measurement model exhibited a fairly good fit with the data collected.

To validate our measurement model, we undertook validity assessments of convergent and discriminant validity. Convergent validity can also be evaluated by examining the factor loading, the composite reliability of measures, and the average variance extracted (AVE) by measures from the results of CFA. Following the recommendation by Hair et al. (1998), factor loading is greater than 0.5 and is considered to be very significant. The composite reliability for all factors in the measurement model was above 0.6 (Fornell and Larcker 1981) and the AVEs were all above the recommended 0.5 (Hair et al. 1998), which means that more than half of the variances observed in the items were accounted for by their hypothesized factors. To examine discriminant validity, we compared the shared variances between factors with the average

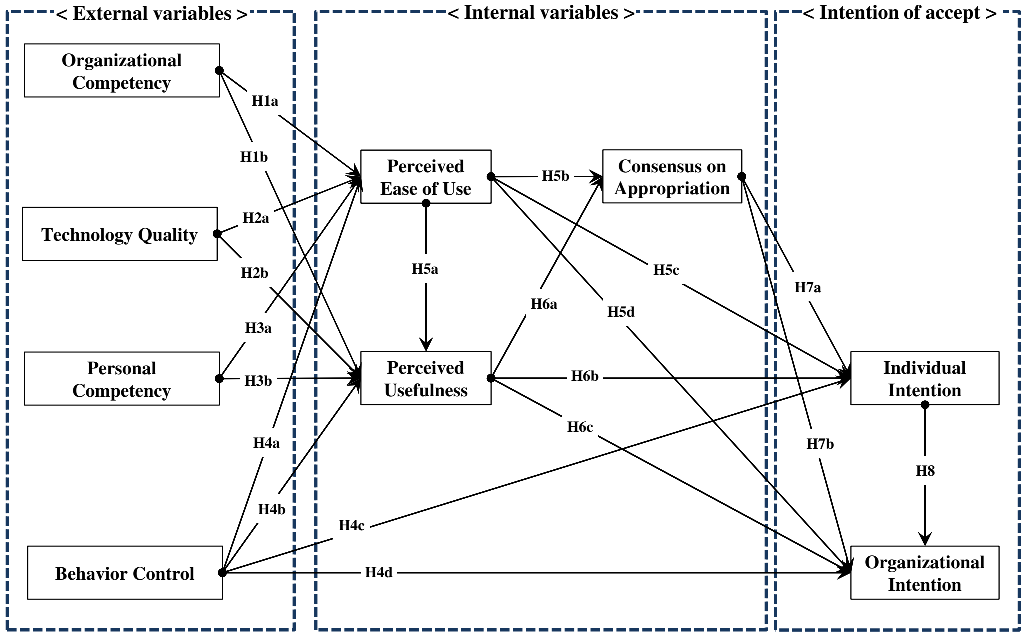

Fig. 6. Research model

variance extracted of the individual factors (Barclay et al. 1995). The AVEs (Table 7) should be greater than the square of the correlations (Table 8) among the constructs (Barclay et al. 1995). That is, the amount of variance shared between a latent variable and its block of indicators should be greater than the shared variance between the latent variables. As indicated in Table 8, the correlation between variables was relatively high. Thus, collinearity diagnosis was conducted to review the multicollinearity between independent variables (see Table 9). The tolerance limit exceeded 0.1, the various inflation factor (VIF) was below 10, and condition index was under 30 (Nunnally and Bernstein 1994). Therefore, multicollinearity was verified and the research model is appropriate.

The discriminant validity test (Table 10) between organizational competency and consensus on appropriation, and between organizational competency and organizational intention of BIM acceptance, was not satisfied. However, the result of EFA is significant (Lee and Yu 2013), and organizational competency consists of detailed items verified by professionals. Thus, organizational competency was not deleted.

Structural Model

We used a similar set of fit indices to examine the structural model (Table 6). A comparison of all fit indices with their corresponding recommended values provided evidence of a good model fit ($x^2 = 2103.125$, with $\mathrm{df} = 963$, $\mathrm{RMR} = 0.181$, $\mathrm{PGFI} = 0.511$, $\mathrm{TLI} = 0.726$, $\mathrm{CFI} = 0.745$, and $\mathrm{RMSEA} = 0.097$). Given an adequate measurement model, the hypotheses can be tested by examining the structural model.

Fig. 7 shows the standardized path coefficients, their significance for the structural model, and the squared multiple correlations (R^2) for an endogenous construct. The standardized path coefficient indicates the strengths of the relationships between the independent and dependent variables. The R^2 value represents the amount of variance explained by independent variables.

As expected, hypothesis H1a is supported ($\gamma = 0.432$). This implies that increased organizational competency is associated with increased perceived ease of use. The influence of technology quality had an impact on perceived usefulness; thus, H2b is supported ($\gamma = 0.27$). For personal competency, hypothesis H3b is supported ($\gamma = 0.243$). This implies that increased technology quality is associated with increased perceived usefulness. Also, hypotheses H4c and H4d are supported ($\gamma = 0.239$, $\gamma = 0.272$, respectively). The influence of behavior control directly affects individual and organizational intention to accept BIM.

Perceived ease of use appears to be a significant determinant of perceived usefulness, and consensus on appropriation; thus, H5a and H5b are supported ($\beta = 0.486$, $\beta = 0.582$, respectively). Perceived usefulness had a significant effect on consensus on appropriation and individual intention to accept BIM; therefore, H6a and H6b are supported ($\beta = 0.212$, $\beta = 0.667$, respectively). Consensus on appropriation had an impact on organizational intention to accept BIM; thus, H7b are supported ($\beta = 0.443$). Finally, increased individual intention to accept BIM was associated with increased organizational intention to accept BIM; so H8 is supported ($\beta = 0.321$).

H1a explained 35.8% of the variance in perceived ease of use. H2b, H3b, and H5a together explained 54.6% of the variance in perceived usefulness. H4c and H6b together explained 53.6% of the variance in consensus on appropriation. H4d, H6c, and H8a together explained 55.2% of the variance in individual intention to accept BIM. H7b and H8 together explained 65% of the variance in organizational intention to accept BIM. The direct, indirect, and total effects of each construct are summarized in Table 11.

Discussion and Limitations

This research systematically analyzes which motivation factors influence individual and organizational acceptance of BIM in terms of increasing the BIM acceptance rate among participating organizations in the construction industry. Subsequently, appropriate factors for evaluating the readiness for BIM acceptance were deduced and studied for their impact mechanisms in both individual and organizational BIM acceptance to suggest a more comprehensive model.

Table 4. Research Hypothesis

Hypotheses	Definition
H1	
a	Organizational competency will positively affect perceived usefulness
b	Organizational competency will positively affect perceived ease of use
H2	
a	Technology quality will positively affect perceived usefulness
b	Technology quality will positively affect perceived ease of use
H3	
a	Personal competency will positively affect perceived usefulness
b	Personal competency will positively affect perceived ease of use
H4	
a	Behavior control will positively affect perceived usefulness
b	Behavior control will positively affect perceived ease of use
c	Behavior control usefulness will positively affect individual intention to accept BIM
d	Behavior control usefulness will positively affect organizational intention to accept BIM
H5	
a	Perceived ease of use will positively affect perceived usefulness
b	Perceived ease of use will positively affect consensus on appropriation
c	Perceived ease of use will positively affect individual intention to accept BIM
d	Perceived ease of use will positively affect organizational intention to accept BIM
H6	
a	Perceived usefulness will positively affect consensus on appropriation
b	Perceived usefulness will positively affect individual intention to accept BIM
c	Perceived usefulness will positively affect organizational intention to accept BIM
H7	
a	Consensus on appropriation will positively affect organizational intention to accept BIM
b	Consensus on appropriation will positively affect individual intention to accept BIM
H8	Individual intention to accept BIM will positively affect organizational intention to accept BIM

Table 5. Characteristics of the Respondents ($N = 114$)

Measure	Frequency	Percentage
Sector of the respondent's organization		
Designer	36	31.58
CM	30	26.32
Contractor	33	28.95
Engineer	15	13.16
Total	114	100
Respondent's average experience		
Construction industry	Approx. 7.5 years	
BIM	Approx. 1.2 years	
BIM-related education or training	Approx. 24.12 h	

This research states that BIM acceptance is possible when an individual is willing to utilize BIM tools or information for their tasks and when their organization is willing to establish a cooperation system by utilizing BIM. Thus, the BIM acceptance model suggested by this research is composed of nine factors,

Table 6. Fit Indices for Research Model

Fit indices	Recommended value	Measurement model	Structural model
X^2/df	≤3.0	2.137	2.184
RMR	≤0.1	0.155	0.181
PGFI	≥0.5	0.512	0.511
TLI	≥0.9	0.737	0.726
CFI	≥0.9	0.758	0.745
RMSEA	≤0.1	0.095	0.097

Table 7. Results of CFA

Latent constructs	Observed indicators	Factor loading	t value	Composite reliability	Average variance extracted
Organizational competency	OC 1	0.793	[a]	0.861	0.411
	OC 2	0.737	0.109		
	OC 3	0.786	0.106		
	OC 4	0.877	0.116		
	OC 5	0.841	0.112		
	OC 6	0.862	0.111		
	OC 7	0.718	0.116		
	OC 8	0.659	0.114		
	OC 9	0.566	0.111		
Technology quality	TQ 1	0.658	[a]	0.862	0.475
	TQ 2	0.742	0.168		
	TQ 3	0.781	0.158		
	TQ 4	0.815	0.151		
	TQ 5	0.908	0.176		
	TQ 6	0.875	0.17		
	TQ 7	0.664	0.155		
Personal competency	PC 1	0.801	[a]	0.888	0.569
	PC 2	0.819	0.096		
	PC 3	0.805	0.095		
	PC 4	0.868	0.095		
	PC 5	0.783	0.1		
	PC 6	0.876	0.094		
Behavior control	BC1	0.677	[a]	0.723	0.347
	BC2	0.595	0.156		
	BC3	0.804	0.174		
	BC4	0.675	0.167		
	BC5	0.833	0.18		
Perceived ease of use	PEU 1	0.838	[a]	0.830	0.619
	PEU 2	0.775	0.114		
	PEU 3	0.868	0.128		
Perceived usefulness	PU 1	0.699	[a]	0.814	0.389
	PU 2	0.526	0.118		
	PU 3	0.771	0.116		
	PU 4	0.673	0.115		
	PU 5	0.81	0.117		
	PU 6	0.616	0.109		
	PU 7	0.707	0.127		
Consensus on appropriation	COA 1	0.923	0.123	0.804	0.674
	COA 2	0.784	0.116		
Individual intention to accept BIM	IIA 1	0.926	[a]	0.857	0.667
	IIA 2	0.929	0.118		
	IIA 3	0.801	0.087		
Organizational intention to accept BIM	OIA 1	0.895	[a]	0.841	0.571
	OIA 2	0.907	0.092		
	OIA 3	0.815	0.215		
	OIA 4	0.806	0.201		

Note: OC = organizational competency; TQ = technology quality; PC = personal competency; PEU = perceived ease of use; PU = perceived usefulness; COA = consensus on appropriation; IIA = individual intention to accept BIM; and OIA = organizational intention to accept BIM.
[a]t value for these parameters were not available because they were fixed for scaling purpose.

Table 8. Correlation Matrix of Factors

	OC	TQ	PC	BC	PU	PEU	COA	IIA	OIA
OC	1								
TQ	0.260[a]	1							
PC	0.454[a]	0.398[a]	1						
BC	0.572[a]	0.102[a]	0.401[a]	1					
PU	0.386[a]	0.499[a]	0.415[a]	0.183[a]	1				
PEU	0.528[a]	0.293[a]	0.359[a]	0.38[a]	0.617[a]	1			
COA	0.654[a]	0.275[a]	0.447[a]	0.426[a]	0.563[a]	0.685[a]	1		
IIA	0.449[a]	0.389[a]	0.741[a]	0.334[a]	0.671[a]	0.487[a]	0.488[a]	1	
OIA	0.646[a]	0.216[a]	0.530[a]	0.524[a]	0.550[a]	0.539[a]	0.704[a]	0.649[a]	1

[a] $p < 0.01$.

Table 9. Diagnosis Result of Multicollinearity

Variables	Condition index	Tolerance	Various inflation factor
OC	10.787	0.481	2.079
TQ	12.578	0.748	1.337
PC	14.311	0.450	2.220
BC	16.476	0.640	1.563
PU	18.220	0.463	2.158
COA	19.897	0.514	1.944
PEU	21.180	0.539	1.856
IIA	29.189	0.371	2.699

Table 10. Results of Discriminant Validity Test

Latent constructs	R^2	Average variance extracted		Discriminant validity
OC-TQ	0.068	0.411	0.475	Acceptable
OC-PC	0.206		0.569	Acceptable
OC-BC	0.327		0.347	Acceptable
OC-PU	0.149		0.389	Acceptable
OC-PEU	0.279		0.619	Acceptable
OC-COA	0.428		0.674	Unacceptable
OC-IIA	0.202		0.667	Acceptable
OC-OIA	0.417		0.571	Unacceptable
TQ-PC	0.158	0.475	0.569	Acceptable
TQ-BC	0.010		0.347	Acceptable
TQ-PU	0.249		0.389	Acceptable
TQ-PEU	0.086		0.619	Acceptable
TQ-COA	0.076		0.674	Acceptable
TQ-IIA	0.151		0.667	Acceptable
TQ-OIA	0.047		0.571	Acceptable
PC-BC	0.161	0.569	0.347	Acceptable
PC-PU	0.172		0.389	Acceptable
PC-PEU	0.129		0.619	Acceptable
PC-COA	0.200		0.674	Acceptable
PC-IIA	0.549		0.667	Acceptable
PC-OIA	0.281		0.571	Acceptable
BC-PU	0.033	0.347	0.389	Acceptable
BC-PEU	0.144		0.619	Acceptable
BC-COA	0.181		0.674	Acceptable
BC-IIA	0.112		0.667	Acceptable
BC-OIA	0.275		0.571	Acceptable
PEU-PU	0.381	0.389	0.619	Acceptable
PEU-COA	0.317		0.674	Acceptable
PEU-IIA	0.450		0.667	Unacceptable
PEU-OIA	0.303		0.571	Acceptable
PU-COA	0.469	0.619	0.674	Acceptable
PU-IIA	0.237		0.667	Acceptable
PU-OIA	0.291		0.571	Acceptable
COA-IIA	0.238	0.674	0.667	Acceptable
PU-OIA	0.496		0.571	Acceptable
IIA-OIA	0.421	0.667	0.571	Acceptable

including external, internal, and acceptance factors that influence the participating organization's intent to accept BIM. The implications of the verification results of the research model are as follows.

Good Model Fit of Research Model

Individual intention to accept BIM and organizational intention to accept BIM constitute more than 50% of the variance. This means that the configuration of constructors is correct. Consequently, it can be said that individual BIM acceptance and organizational BIM acceptance evaluation factors are appropriate for representing the level of BIM acceptance. We also obtained evidence that there are strong connections between the nine constructs, supporting the hypothesized relationships. External variables, which impact BIM awareness among organizations or individual, have a positive impact on perceived usefulness and perceived ease of use. They also positively affect individual intent to accept BIM and consensus on appropriation, which is agreement on using BIM among organizational members. As consensus on appropriation is expanding, organizational intent to accept BIM increases. Therefore, both individual and organizational intent to accept BIM is necessary for complete intention to accept BIM. To achieve this, efforts to improve perceived usefulness and ease of use are required.

Relationship between Internal Variables and Intent to Accept BIM

The results of the hypothesis test on perceived usefulness, perceived ease of use, and individual intent to accept BIM show that perceived usefulness has a significant impact on individual intent to accept BIM. On the other hand, perceived ease of use only showed an indirect influence on individual intent to accept BIM through perceived usefulness. Therefore, the perceived usefulness of BIM utilization on individual tasks or cooperation capacity must be high in order to increase individual intent to accept BIM. To achieve this, the individual must perceive that their tasks and cooperative work can be done without difficulty by using BIM.

We assumed that full effectiveness of BIM utilization can only be achieved with both individual and organizational acceptance of BIM. Thus, this model suggests the need for organizational intent to accept BIM, in addition to individual intent to accept BIM, unlike in previous acceptance models. The results of the relationship hypothesis test on perceived usefulness, perceived ease of use, and organizational intent to accept BIM show that neither perceived usefulness nor perceived ease of use have a direct relationship with organizational intent to accept BIM; however, they do have an indirect relationship through consensus on appropriation. The level of consent among organizational members has the largest impact on BIM acceptance from the organizational perspective. This means that organizational intent to accept BIM can be increased not only by individuals recognizing the usability of BIM on their tasks and cooperative work, but also by recognizing a certain level of consent among organizational members. Finally, individual and organizational intent to accept BIM have a significant relationship. This means that high individual intent to accept BIM and high consensus on appropriation are required in order to achieve high organizational intent to accept BIM.

Relationship between External Variables, Perceived Usefulness, and Perceived Ease of Use

The results of the hypothesis test on the relationship of external variables, perceived usefulness, and perceived ease of use that impact BIM acceptance show that organizational competency

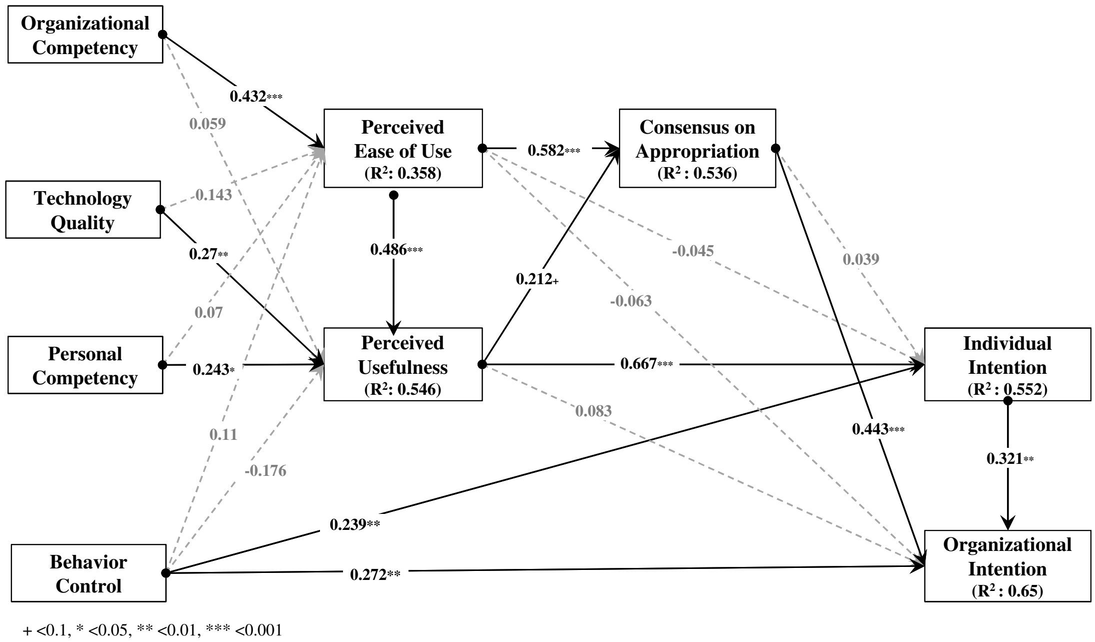

Fig. 7. Results of hypothesis testing

Table 11. Direct, Indirect, and Total Effects

Latent constructs	Total effect					Direct effect					Indirect effect				
	PEU	PU	COA	IIA	OIA	PEU	PU	COA	IIA	OIA	PEU	PU	COA	IIA	OIA
OC	0.432	0.269	0.309	0.172	0.187	0.432	0.059	0	0	0	0	0.210	0.309	0.172	0.187
TQ	0.143	0.340	0.155	0.226	0.161	0.143	0.270	0	0	0	0	0.070	0.155	0.226	0.161
PC	0.070	0.277	0.099	0.186	0.122	0.070	0.243	0	0	0	0	0.034	0.099	0.186	0.122
BC	0.110	−0.122	0.038	0.154	0.321	0.110	−0.176	0	0.239	0.272	0	0.054	0.038	−0.085	0.049
PEU	0	0.486	0.685	0.306	0.379	0	0.486	0.582	−0.045	−0.063	0	0	0.103	0.351	0.442
PU	0	0	0.212	0.676	0.394	0	0	0.212	0.667	0.083	0	0	0	0.008	0.311
COA	0	0	0	0.039	0.455	0	0	0	0.039	0.443	0	0	0	0	0.013
IIA	0	0	0	0	0.321	0	0	0	0	0.321	0	0	0	0	0

has the most significant and largest impact on perceived ease of use. On the other hand, personal competency (especially technology quality) has a significant impact on perceived usefulness. This indicates that perceived ease of use of BIM when performing individual tasks or cooperative work is higher when the organization is more flexible and active in accepting new technology. This also indicates that to increase perceived usefulness of BIM, the agent using BIM must be active and have no difficulty in accepting new technology; moreover, the quality of the outcome after using BIM must be high. However, behavior control, which indicates external and internal pressure on BIM utilization, has no impact on internal factors, but does impact on external factors (such as individual and organizational intent to accept BIM). It has a significant relationship with the intent to accept BIM, especially with organizational intent. This indicates that in conditions where BIM use is unavoidable, such as in a demand from the ordering body, the organizational intent to accept BIM increases without regard to the usefulness of BIM, consensus among members, or individual intent to accept BIM.

Implications of this Model for Individuals and Organizations

This model identifies factors affecting BIM acceptance from an individual and organizational perspective, and analyzes relationships between the factors. Therefore, the model can be used to evaluate BIM acceptance readiness of an individual and an organization. The evaluation results of BIM acceptance readiness can also be used to develop a BIM acceptance strategy that is suitable for each individual or organization. The BIM acceptance strategy may include the following: what factors should be more importantly managed over other factors affecting BIM acceptance; what improvement level of the factors is effective; and finally, what development order of the factors is effective. The strategies can provide guidance to an individual and an organization to come up with an effective improvement plan. This research is significant in providing a base that enables the above series of processes.

Limitations and Future Research

This research is based on an investigation in a particular country. Thus, the interpretation of the results should be confined to South Korea or to countries with similar settings. Further, this research was only conducted in targeted organizations that were already utilizing BIM, and no information was collected from nonadopters. The findings of this research, however, can be similarly considered as important factors for nonadopters or other countries.

This means that the identified effective factors can be accepted and raised as a precondition of BIM adoption.

Future research should address the following: improvement of the R^2 value and continual development of the research model by adding various factors; investigation about the hidden meaning of nonsignificant hypotheses, subfactors which comprise the hypotheses that are identified, and relationships between the subfactors; and finally, how to convert nonadopters into adopters, and perceptions related to BIM between adopters and nonadopters.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology(2013-030794), The present Research has been conducted by the Research Grant of Kwangwoon University in 2013.

References

Agarwal, R., and Prasad, J. (1997). "The role of innovation characteristics and perceived voluntariness in the acceptance of information technologies." *Decis. Sci.*, 28(3), 557–582.

Ajzen, I. (1985). "From intentions to actions: A theory of planned behavior." *Action control, SSSP Springer series in social psychology*, Springer, Berlin, 11–39.

Aksorn, T., and Hadikusumo, B. H. W. (2008). "Critical success factors influencing safety program performance in Thai construction projects." *Saf. Sci.*, 46(4), 709–727.

AMOS 20.0 [Computer software]. (2011). IBM.

An, S. J., Lee, H. S., Park, M. S., and Kim, W. Y. (2009). "Object-oriented modeling of construction operations for schedule-cost integrated planning based on BIM." *J. Architect. Inst. Korea*, 25(12), 165–174.

Anderson, J. C., and Gerbing, D. W. (1988). "Structural equation modeling in practice: A review and recommended two-step approach." *Psychol. Bull.*, 103(3), 411–423.

Bandura, A. (1977). *Social learning theory*, Prentice Hall, Upper Saddle River, NJ.

Barclay, D., Thompson, R., and Higgins, C. (1995). "The partial least squares (PLS) approach to causal modeling: Personal computer adoption and use as an illustration." *Technol. Stud.*, 2(2), 285–309.

Barki, H., and Hartwick, J. (2001). "Communications as a dimension of user participation." *IEEE Trans. Prof. Comm.*, 44(1), 21–36.

Bartlett, M. S. (1954). "A note on the multiplying factors for various chi square approximations." *J. Roy. Stat. Soc. B*, 16(2), 296–298.

Baumgartner, H., and Homburg, C. (1996). "Application of structural equation modeling in marketing and consumer research: A review." *Int. J. Res. Market.*, 13(2), 139–161.

Choi, H. S. (2010). "An analysis about factors affecting inactiveness of BIM introduction in the construction industry." Master's thesis, Hanyang Univ., Seoul.

Chung, B. Y., Skibniewski, M. J., and Kwak, Y. H. (2009). "Developing ERP systems success model for the construction industry." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(2009)135:3(207), 207–216.

Chung, B. Y., Skibniewski, M. J., Lucas, H. C., and Kwak, Y. H. (2008). "Analyzing enterprise resource planning system implementation success factors in the engineering, construction industry." *J. Comput. Civ. Eng.*, 10.1061/(ASCE)0887-3801(2008)22:6(373), 373–382.

Davis, F. D. (1989). "Perceived usefulness, perceived ease of use, and user acceptance of information technologies." *MIS Q.*, 13(3), 319–340.

Davis, F. D., Bagozzi, R., and Warshaw, P. R. (1989). "User acceptance of computer technology: A comparison of two theoretical models." *Manage. Sci.*, 35(8), 982–100.

Deci, E. L. (1975). *Intrinsic motivation*, Plenum Press, New York.

Deci, E. L., and Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*, Plenum, NewYork.

Deci, E. L., and Ryan, R. M. (1987). "The support of autonomy and the control of behavior." *J. Pers. Soc. Psychol.*, 53(6), 1024–1037.

DeLone, W. H., and McLean, E. R. (1992). "Information system success: The quest for the dependent variable." *Inform. Syst. Res.*, 3(1), 60–95.

DeLone, W. H., and McLean, E. R. (2003). "The DeLone and McLean model of information system success: A ten-year update." *J. Manage. Inform. Syst.*, 19(4), 9–30.

Eastman, C., Teicholz, P., Rafael, S., and Kathleen, L. (2008). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractor*, John Wiley and Sons, New York.

Fishbein, M., and Ajzen, I. (1975). *Belief, attitude, intention and behavior: An introduction to theory and research*, Addison-Wesley Publication, Boston.

Fornell, C., and Larcker, D. F. (1981). "Evaluating structural equation models with unobservable variable and measurement error." *J. Market. Res.*, 18(1), 39–50.

Froese, T. M., and Yu, K. Q. (1999). "Industry foundation class modelling for estimating and scheduling." *Durability of Building Materials and Components 8: Information technology in construction*, M. A. Lacasse, D. J. Vanier, eds., NRC Research Press, Ottawa, Canada, 2825–2835.

Fu, J. R., Farn, C. K., and Chao, W. P. (2006). "Acceptance of electronic tax filing: A study of taxpayer intentions." *Inform. Manage.*, 43(1), 109–126.

Gerardine, D., and Marshall, S. P. (1992). "Microlevel structuration in computer-supported group decision making." *Hum. Comm. Res.*, 19(1), 5–49.

Gilligan, B., and Kunz, J. (2007). "VDC Use in 2007: Significant value, dramatic growth, and apparent business opportunity." *CIFE Technical Rep. No. TR171*, Stanford Univ., Palo Alto, CA.

Goddard, R. D., Hoy, W. K., and Woolfolk, H. A. (2000). "Collective teacher efficacy: Its meaning, measure, and effect on student achievement." *Am. Educ. Res. J.*, 37(2), 479–507.

Goodhue, D. L., and Thompson, R. L. (1995). "Task-technology fit and individual performance." *MIS Q.*, 19(2), 213–236.

Hair, J. F., Ronald, L., Tatham, R. E. A., and William, B. (1998). *Multivariate data analysis*, Prentice-Hall International, NJ.

Hong, W., Thong, J. Y. L., Wong, W. M., and Tam, K. Y. (2002). "Determinants of user acceptance of digital libraries: An empirical examination of individual differences and systems characteristics." *J. Manage. Inform. Syst.*, 18(3), 97–124.

Hoy, W. K., Sweetland, S. R., and Smith, P. A. (2002). "Toward an organizational model of achievement in high schools: The significance of collective efficacy." *Educ. Admin. Q.*, 38(1), 77–93.

Jiang, J. J., Klein, G., Chen, H. G., and Lin, L. (2002). "Reducing user-related risks during and prior to system development." *Int. J. Proj. Manage.*, 20(7), 507–515.

Kaiser, H. F. (1970). "A second generation little jiffy." *Psychometrika*, 35(4), 401–415.

Lee, A. S. (1994). "Electronic mail as a medium for rich-communication: An empirical investigation using hermeneutic interpretation." *Manage. Inform. Syst. Q.*, 18(2), 143–157.

Lee, C. J., Lee, G., and Won, J. S. (2009). "An analysis of the BIM software selection factor." *J. Architect. Inst. Korea*, 25(7), 53–63.

Lee, S. H., An, B. J., Kim, J. H., Kim, K. H., Lee, Y. S., and Kim, J. J. (2007). "An analysis on affecting factors about lowly using 3D CAD by using the AHP." *J. Constr. Eng. Manage.*, 8(6), 188–196.

Lee, S. K., and Yu, J. H. (2013). "Exploring the key factors for BIM acceptance in construction organizations." *5th Int. Conf. on Construction Engineering & Project Management (ICCEPM)*.

Li, B., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005). "Critical success factors for PPP/PFI projects in the UK construction industry." *Constr. Manage. Econ.*, 23(5), 459–471.

Marshall, S. P., and Gerardine, D. (1994). "Capturing the complexity of advanced technology use: Adaptive structuration theory." *Organ. Sci.*, 5(2), 121–147.

Mendez, R. (2006). "The building information model in facilities management." Master's dissertation, Worcester Polytechnic Univ., Worcester, MA.

Moon, J. W., and Kim, Y. G. (2001). "Extending the TAM for a world wide web context." *Inform. Manage.*, 38(4), 217–230.

Moore, G. C., and Benbasat, I. (1991). "Development of an instrument to measure the perceptions of adopting an information technology innovation." *Inform. Syst. Res.*, 2(3), 192–222.

Myers, B. L., Kappelman, L. A., and Prybutok, V. R. (1997). "A comprehensive model for assessing the quality and productivity of the information systems function: Toward a theory for information systems assessment." *Inform. Resour. Manage. J.*, 10(1), 6–25.

Nam, K. M., Kim, D. W., Cho, H. H., and Kang, K. I. (2008). "Usability analysis on PMIS using technology acceptance model." *Proc., Korea Institute of Construction Engineering and Management*, Vol. 11, 175–179.

National Institute of Standards and Technology. (2004). *General building information handover guide*.

Newton, R. S. (1995). "Inadequate interoperability in construction wastes 415.8 billion annually." *AEC News.com 13*, Article 342.

Norusis, M. J. (1992). *SPSS for windows: Professional statistics, release 5*, SPSS, Chicago.

Nunnally, J. C., and Bernstein, I. H. (1994). *Psychometric theory*, McGraw-Hill, New York.

Nunnalyy, J. C. (1978). *Psychometric theory*, McGraw-Hill, New York.

Pallant, J. (2001). *SPSS survival manual*, Open University Press, Philadelphia.

Park, Y. J., Won, S. K., Han, C. H., and Lee, J. B. (2011). "A study on 3D BIM collaborative approximate estimating model of structural work for apartment projects." *J. Architect. Inst. Korea*, 27(6), 123–130.

Patrick, Y. K. C., and Paul, J. H. H. (2002). "Investigating healthcare professionals' decisions to accept telemedicine technology: An empirical test of competing theories." *Inform. Manage.*, 39(4), 297–311.

Paul, L., John, I., and Pierre, C. (2003). "Why do people use information technology? A critical review of the technology acceptance model." *Inform. Manage.*, 40(3), 191–204.

Pitt, L. F., Watson, R. T., and Kavan, C. B. (1995). "Service quality: A measure of information system effectiveness." *MIS Q.*, 19(2), 173–187.

Saga, V. L., and Zmud, R. W. (1994). "The nature and determinants of IT acceptance, routinization and infusion." *Proc., IFIP TC8 Working Conf. on Diffusion, Transfer and Implementation of Information Technology*, 67–86.

Seddon, P. B. (1997). "A respecification and extension of the DeLone and McLean's model of IS success." *Inform. Syst. Res.*, 8(3), 240–253.

Seddon, P. B., and Kiew, M. Y. (1996). "A partial test and development of DeLone and McLean's model of IS success." *Australasian J. Inform. Syst.*, 4(1), 90–109.

SmartMarket Report. (2012). *The business value of BIM for infrastructure*, McGraw-Hill Construction, Miami.

Taylor, S., and Todd, P. A. (1995). "Understanding information technology usage: A test of competing models." *Inform. Syst. Res.*, 6(2), 144–176.

Tulke, J., Nour, M., and Beuke, K. (2008). "Decomposition of BIM objects for scheduling and 4D simulation." *Proc., 7th European Conf. on Product and Process Modelling*, 653–660.

Venkatesh, V. (1999). "Creation of favourable user perceptions: Exploring the role of intrinsic motivation." *MIS Q.*, 23(2), 239–260.

Venkatesh, V., and Bala, H. (2008). "TAM 3: Advancing the technology acceptance model with a focus on interventions." *Decis. Sci.*, 39(2), 273–315.

Venkatesh, V., and Davis, F. D. (2000). "A theoretical extension of the technology acceptance model: Four longitudinal field studies." *Manage. Sci.*, 46(2), 186–204.

Wang, Y. S., and Liao, Y. W. (2008). "Assessing e-Government systems success: A validation of the DeLone and McLean model of information systems success." *Govern. Inform. Q.*, 25(4), 717–733.