Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2020 Volume 26 Issue 3: 259–277
https://doi.org/10.3846/jcem.2020.12176

# USING A TAM-TOE MODEL TO EXPLORE FACTORS OF BUILDING INFORMATION MODELLING (BIM) ADOPTION IN THE CONSTRUCTION INDUSTRY

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Received 23 March 2018; accepted 20 September 2019

**Abstract.** Building Information Modelling (BIM) has been adopted as the main technology in the construction qiindustry in many developed countries due to its notable advantages. However, its applications in developing countries are limited. This paper aims to investigate factors which impact on BIM adoption in the construction industry. Twelve external variables were identified by an integrated TAM (Technology Acceptance Model) and TOE (Technology Organization Environment) framework and a systematic review of past studies. A survey was conducted in development, construction, design and consulting companies to investigate the impacts of these 12 external variables on BIM adoption. Using the interval Decision Making Trial and Evaluation Laboratory (DEMATEL) method, retrieved 120 completed questionnaires were analysed. The "Requirements from national policies" was found to be the most significant driving variable of BIM adoption by investigated companies. A further simulation analysis revealed that the "Intention to Use" BIM varied significantly with the change of "Requirements from national policies", "Standardization of BIM", and "Popularity of BIM in the industry". The results lead to the conclusion that government incentives play critical roles in BIM adoption in China. Policy makers could put more efforts into motivation strategies, standardization measures, and BIM culture cultivation to promote BIM applications in the construction industry.

**Keywords:** building information modelling, technology acceptance model, TAM-TOE model, decision making trial and evaluation laboratory, construction organization.

## Introduction

Rapid development of construction industry has brought many challenges to the traditional construction mode. These challenges are from various aspects, such as complex construction technology, enormous investment, tight schedule, multiple stakeholders and mass information (Li et al., 2014a). Researchers and practitioners have been engaged on promoting implementation of building information modeling (BIM) in the construction industry to deal with these emerged issues.

BIM technology, which aims to integrate intelligence and informatization, has been widely applied in civil engineering and related area over the past decades and has brought remarkable innovations to construction industry (Yalcinkaya & Singh, 2015). Advantages of BIM have been recognized in developed countries, particularly when being applied in large and complex projects which involve numerous participants (Feng, 2014). These advantages include: reducing material wastage, decreasing number of alterations, improving design and construction quality, increasing communication efficiency, and promoting lean management of cost, quality and time (Li et al., 2014b; Morin, 2015; Doumbouya et al., 2016; Haraguchi, 2016). However, the adoption of current BIM technology is much slower than expected. Barriers have been noted in implementation, such as: poor compatibility in application, weak willingness of cooperation among project participants, shortage of professionals and difficulty in coordination (Azhar, 2011; Zheng et al., 2016).

Succar and Kassem (2015) have divided BIM implementation into three phases: modelling, collaboration and integration. In UK, the application and development of BIM is rapid under the strong promotion of the government. Eadie et al. (2015) have conducted telephone interviews and online-survey on selected British architectural

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BIM experts and found that application of BIM has already been at the second stage in the UK, which is the collaboration stage. A report from McGraw-Hill Construction (2012) shows that BIM technology has been adopted in almost 71% of construction industry in North America. In Singapore, the government required that BIM should be applied in all construction projects by 2015. BIM is mostly applied in design and construction stages from 2010 to 2015 but the application of BIM in facility management is relevant limited (Edirisinghe & London, 2015; Shen et al., 2016). Park et al. (2015) have investigated BIM adoption in the civil engineering industry in South Korea and found that BIM has not been involved in the whole project life cycle. In Japan, BIM is highly localized. It was firstly introduced to some government project as a pilot and then gradually being promoted to the whole industry. Some large-scale and complex have adopted BIM technology to deal with project coordination and information management, but there are still some problems in the application process (Yamazaki et al., 2014). Forsythe et al. (2015) conducted a study on information asymmetry of construction projects in Australian and found that the current BIM application in Australia could reduce the information asymmetry to a certain extent but has not reached the stage of maturity yet. Bosch et al. (2015) conducted 21 semi-structured interviews with construction project owners, operators, software companies, suppliers and contractors regarding to the added value of BIM technology and found that BIM has been mostly applied at the planning, development and construction stages in entire project life cycle in Netherlands.

In recent years, BIM has been greatly promoted by governments and private sectors in China, but the acceptance and adoptions are staying at a very early stage (Construction Enterprise BIM Technology Application Status Research Group, 2015; MOHURD, 2015), and has made no substantial changes to the traditional construction industry so far (Shanghai Construction Industry Association & Shanghai Luban Consulting Company, 2014; Le et al., 2018). Most BIM applications in China are at the modelling stage and only a few projects have involved collaboration activities. BIM implementation in organizations is limited and only involved in designing and construction in the entire project cycle (Lyu et al., 2017). Cao et al. (2015) investigated BIM application in 106 construction projects in China from 2007 to 2013. They found that a majority of projects has used BIM in clash detection (about 83.96%) in construction stage and 3D visualization (about 76.42%) in design stage, followed by construction system design (75.47%), collaborative design (66.04%) and design proposal (63.21%), while site analysis and on-site material management are the barely touched areas. They also found that BIM application in most stages is 'occasionally' rather than "frequently" except clash detection and 3D visualization.

According to the "China construction industry information development report: in-depth application and development of BIM" (MOHURD, 2015), the application of BIM is towards integration, synergy and multi-level development, from the designing stage to the construction stage and from technical application to management integration. The application theme shifts from individual to multi-party and the application scope changes from special projects to general projects. BIM applications are diversified and can effectively improve the cooperative relationships among the participants, and at the same time, organizational factors and other factors could affect the synergy relationships (Liu et al., 2017). Acceptance of BIM technology is not limited on individual's willingness to use for specific task, but also the organization's intention to use it for information management in the whole life cycle of the project (Lee et al., 2013).

Research on influential factors of BIM adoption has been extensive, but mostly focused on individual attitudes and neglecting the correlations between different factors. Since multiple stakeholders are involved, the final decision on BIM implementation is usually determined by whether it could bring comparable benefits for the company or whether it is compatible to the current business rather than purely individuals' using experience. In consequence, this paper focuses on factors influencing adoption of BIM by organizations rather than individuals. It developed a TAM-TOE model for BIM acceptance based on the Technology Acceptance Model (TAM) and the Technology-Organization-Environment (TOM) framework. An Interval DEMATEL method was applied to analyze the relationships between a set of factors and their influencing levels to each other. Key factors were identified for BIM adoption in organizations and relevant strategic and policy implications were suggested based on the results.

The remainder of the paper is structured as follows. In Section 1, an improved TAM-TOE model is developed for BIM adoption. The DEMATEL method is introduced in Section 2 and Section 3 identifies internal and external variables based on literature review and the best judgement and demonstrates the relations between. Section 4 discusses the data collection and data analysis methods. Key variables which impact on BIM adoption are identified based on the DEMATEL method. Section 5 introduces an interactive simulation to analyze the variation of target variables with value changes of eight key driving variables. Section 6 provides strategic recommendations on BIM adoption in construction organizations based on the results.

## 1. An integrated TAM-TOE framework for BIM adoption

### 1.1. The technology acceptance model (TAM)

The technology acceptance model (TAM) was developed by Davis et al. (1989) based on the Theory of Reasoned Action (TRA) in 1989 (as seen in Figure 1). Authors believed that adoption of a new technology (actual system use) is determined by people' behavioral intention to use, which is related to their perceived usefulness and ease of

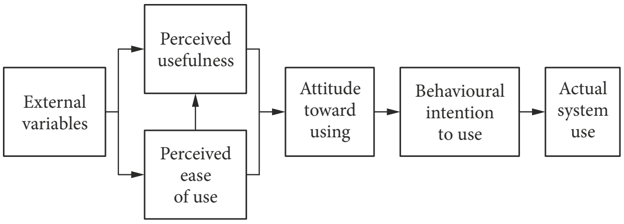


Figure 1. Technology acceptance model (TAM)

use. In the meantime, the perceived ease of use has an impact on perceived usefulness, and the perceived usefulness and ease of use are affected by various external variables.

TAM is one of the most influential and moderate theoretical models of users' acceptance and use of technology. It has strong explanatory ability and is easy to understand, thus becomes the most popular model that has been applied across various subjects. TAM was expanded to TAM2 by Venkatesh and Davis in 2000 with an inclusion of social influence processes, cognitive instrumental processes and a detailed account of key forces underlying judgement of perceived usefulness and behavioral intention (Venkatesh & Davis, 2000). Later in 2003, Venkatesh et al. (2003) identified and discussed eight models related to behavioral intention to use information technology and proposed the Unified Theory of Acceptance and Use of Technology (UTAUT). And in 2008, TAM3 was proposed by Venkatesh and Bala (2008) based on TAM2 with an inclusion of the effects of trust and perceived risk on system use.

Different models have been applied under different circumstances. Table 1 gives a summary on the advantages and limitations of these models.

The comparison between TAM, TAM2, UTAUT and TAM3 in the above section leads to the conclusion that TAM has wider application than the other models which have more restrictive definitions on external variables and are preferable for studying some specific information technologies. TAM has been mostly applied in three research areas: task-related information systems, e-commerce information systems, and hedonic information systems (Hsiao & Yang, 2011). It has also been applied in studying the acceptance of BIM in organizations. For example, Lee et al. (2013) has combined the TAM, the information success model and the motivation model, and used the structural equation model (SEM) to explore the motivation factors of BIM adoption in construction organizations.

This paper uses TAM as the basic model for studying acceptance of BIM technology within organizations or companies, as the external variables should be selected under the consideration of the characteristics of BIM application rather than being constrained by predefined variables of models.

### 1.2. The Technology-Organization-Environment framework (TOE)

The Technology-Organization-Environment framework (TOE) was introduced when selecting external variables of BIM adoption in this study. The TOE framework was proposed by Tornatzky and Fleischer (1990) and models the influences of technological, the organizational and the environmental context on the process of adopting and implementing technological innovations by a firm (Drazin, 1991). The technological context refers to internal and external technologies that are currently applied by the organization and those available in the market but not yet used by the company. The organizational context refers to the company size, organizational structure and human resource and the environmental context covers factors outside the control of the organization such as competition, partners and the industry environment.

The TOE framework provides a systematic classification of influencing factors and has been widely applied in existing technology adoption studies (Liu et al., 2011; Xu, 2012; Ahmi et al., 2014; Gangwar et al., 2015). In addition to the three dimensions of context, Songer et al. (2001) suggested to introduce economic factors into the technology adoption framework, considering that firms may attempt to use the information technology if at a low cost. Extreme high initial investment will directly impact on organizations' decisions due to associated high risk. Based on above, this study includes the economic context as the fourth dimension of factors for the TOE-based framework of BIM technology (as seen in Figure 2).

Table 1. Comparison of TAM models

| Model | Advantage | Disadvantage |
|---|---|---|
| TAM | Is simple, widely applied and most influential; Provides flexibility for researchers to select external variables according to study area. | 1. Does not include social impact factors; 2. Is lack of consistent criteria for selecting external variables. |
| TAM2 | Has definition of external variables which impact on perceived ease of use; Has stronger explanation capability than TAM. | Does over-emphasize recognitions of tools and neglect humans' internal motivation. |
| UTAUT | 1. Is a universal model; 2. Has strong explanation capability. | 1. Has restriction on research hypothesis (UTAUT is built on the assumption that the application of the tool/system would bring positive consequences. The model doesn't include the relationship between users' acceptance of the information technology and corresponding results). |
| TAM3 | Has extended TAM2 by synthesizing external factors which impact on perceived usefulness. | Has limited application as the model sets a detailed list of external variables. |

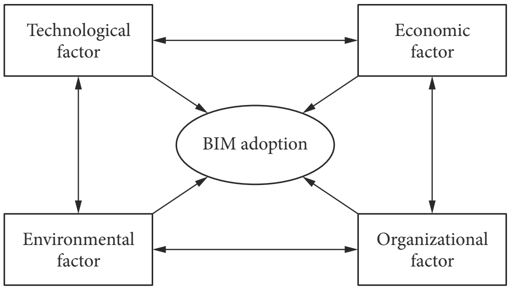


Figure 2. Improved TOE framework of BIM technology

### 1.3. An integrated TAM-TOE BIM adoption model

The Technology Acceptance Model and Technology Organization Environment Framework have been widely applied in innovation and information technology adoption studies. TAM has flexibility in selecting external variables and could capture the individuals' acceptance behaviors, while TOE considers the technical, organizational and environmental factors which impact on technology acceptance and adoption at organizational level. Integrating TAM and TOM could combine the advantages of the two models and capture the adoption behaviors at different levels. For example, Gangwar et al. (2015) have combined TAM and TOE models and applied them to explore the cloud adoption mechanism at organizational level. Liu et al. (2011) integrated the TOE and TAM models and analyzed the system factors which influence the adoption of ERP in manufacturing companies. Xu (2012) established the UTAUT-TOE technology acceptance model framework and analyzed the factors affecting IT adoption.

Existing studies on BIM have mainly focused on the barriers in adoption or individuals' perceptions and acceptance (Li, 2014; Tian, 2014; Li, 2015; Rogers et al., 2015; Singh & Holmström, 2015; Succar & Kassem, 2015; Qin et al., 2016). However, different from traditional IT technology, BIM relies more on collaborative work rather than individual practice, thus the organization plays a key role in application. This study urged that exploring the motivation of enterprise in BIM adoption could provide some implications from decision makers' perspectives. The revised TOE model expands the external variables of the TAM model on four aspects at organizational level. And the TAM-TOE model of BIM adoption not only reflects the commonality of information technology adoption but also highlights the characteristics of BIM technology.

Combining the TAM in Figure 1 with the TOE framework in Figure 2, an integrated TAM-TOE model for BIM technology was developed as seen in Figure 3.

## 2. The DEMATEL method using interval numbers

Decision Making Trial and Evaluation Laboratory (DEMATEL) was developed by the Bottelle Memorial Institute of Geneva in 1971, aiming to solve complex and intertwined problems. It is based on the graph theory and uses matrix structures to model pairwise relationships between influence factors of a complicated system.

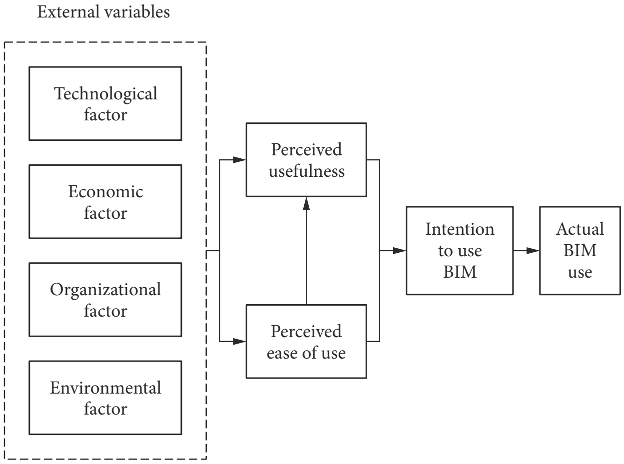


Figure 3. The integrated TAM-TOE model of BIM technology

The influence degrees of each factor on other factors are calculated through their logical relationships in the system to form the direct influence matrix, then the cause and center degree of each factor is calculated to determine the causes and effects between the factors. This method can visually demonstrate the logical relationships between factors through determinant calculus and can simplify complex problems. Therefore, DEMATEL is an effective method for factor analysis and identification, which makes full use of the experience and knowledge of experts in complex social problems, especially in a system with uncertain causal relationships.

It has been preferred by researchers in analyzing factors which are interacted with each other (Sheppard et al., 1988). For example, Sun (2015) used DEMATEL as a primary method to analyze the key factors which lead to the success of EDA businesses and proposed some practical strategies to improve management performance of EDA businesses based on the results. Lee et al. (2010) adopted DEMATEL to calculate the causal relationships and interaction levels between TAM2 variables and identify the core variables. Based on the results they gave suggestions on improving management when promoting a new technology. Scholars have also attempted to improve the DEMATEL method to make it more applicable. Tseng (2009) extended DEMATEL method by integrating fuzzy measure on assessing hotel service quality perceptions. They used the de-fuzzification method to transfer vagueness and subjective linguistic language information into crisp values and effectively assessed the group perceptions. Different group perceptions were integrated into a compromised cause and effect model of hotel service quality in uncertainty. Gao and Lu (2014) combined the traditional DEMATEL with interval numbers, which breaks its limitation on evaluating relationships between intervened factors using only real numbers.

Considering that real numbers are incapable to capture the complicated and fuzzy interactions between factors in the BIM TAM model accurately and scientifically, this study used DEMATEL based on interval numbers.

Firstly, the logical direct relationships between factors were captured through survey questions to develop an initial direct-relation matrix, and based on which, a total relation matrix was derived. Then four indices of each factor were measured including: the influencing degree (D), the influenced degree (R), the centrality degree and the causal degree. In the last, a comprehensive analysis and evaluation were conducted on the relationships among all the influencing factors in the TAM-TOE BIM acceptance framework.

DEMATEL outperforms the structural equation model, principal component analysis and the analytic hierarchy process from three aspects: (1) the method could effectively analyze the multi-level causal correlations between external and internal variables in the adoption of BIM technology, while the other three methods rarely take into account the direct hierarchy of each dimension and causal connections; (2) the centrality and cause indicators formed by DEMATEL during the analysis process are not available in other methods. The centrality index can be used as the weight of each dimension, and the cause index can establish the causal connection between the dimensions; and (3) the relation matrix created by DEMATEL analysis could be used to perform relevant simulation analysis on the actual management activities. However, what should be noted is the subjectivity exists in establishing the weighting matrix between dimensions in the process.

### 2.1. Interval numbers

Interval numbers reflect uncertainties and are expressed by intervals. The value of an interval number is determined by a lower limit and an upper limit and it is a real number when the lower limit equals the upper limit. An interval number $\otimes x$ can be expressed as:

$$x \in \left[\underline{\otimes}, \overline{\otimes}\right].$$

$x$ is an interval number with a range from the lower limit $\underline{\otimes}$ to the upper limit $\overline{\otimes}$. Three steps are involved to turn interval numbers into crisp values (Tseng, 2009), supposing that the impact of $i^{\text{th}}$ variable on $j^{\text{th}}$ variable could be assessed by $k^{\text{th}}$ evaluator. Firstly, the lower limits and upper limits of interval numbers are normalized by Eqns (1) and (2):

$$\widetilde{\underline{\otimes}x_{ij}^{k}} = \left(\underline{\otimes}x_{ij}^{k} - \min \underline{\otimes}x_{ij}^{k}\right) / \Delta_{\min}^{\max}; \tag{1}$$

$$\widetilde{\overline{\otimes}x_{ij}^{k}} = \frac{\left(\overline{\otimes}x_{ij}^{k} - \min \overline{\otimes}x_{ij}^{k}\right)}{\Delta_{\min}^{\max}}, \tag{2}$$

where $\Delta_{\min}^{\max} = \max \overline{\otimes}x_{ij}^{k} - \min \underline{\otimes}x_{ij}^{k}$, and then total normalized crisp value is compute using Eqn (3):

$$Y_{ij}^{k} = \frac{\left(\widetilde{\underline{\otimes}x_{ij}^{k}}\left(1 - \widetilde{\underline{\otimes}x_{ij}^{k}}\right) + \left(\widetilde{\overline{\otimes}x_{ij}^{k}} \times \widetilde{\overline{\otimes}x_{ij}^{k}}\right)\right)}{\left(1 - \widetilde{\underline{\otimes}x_{ij}^{k}} + \widetilde{\overline{\otimes}x_{ij}^{k}}\right)}. \tag{3}$$

Finally, the crisp value is calculated by Eqn (4):

$$z_{ij}^{k} = \min \underline{\otimes}x_{ij}^{k} + Y_{ij}^{k} \Delta_{\min}^{\max}. \tag{4}$$

### 2.2. DEMATEL method based on interval numbers

According to literature (Tseng, 2009; Lee et al., 2010; Gao & Lu, 2014; Sun, 2015), the calculation steps of interval number DEMATEL are summarized as follows.

Firstly, the influence variables of the system $(F_1, F_2, \ldots, F_n)$ are identified from research questions, literature or professional opinions. The influence relationships between variables are sorted out. Then a direction diagram is establish based on the direct relationships between variables. For example, in the system, if $F_i$ directly influences $F_j$, then an arrow which originates from $F_i$ and points to $F_j$ is drawn. In this study, interval numbers are used to describe the influence levels between $F_i$ and $F_j$. As seen in Table 2, five interval numbers indicating five degrees of relationship are listed, with [0, 0] indicating "No Relation" and [3, 4] meaning "Extremely Strong" relationship.

Table 2. Influence levels and respective interval numbers

| Influence level | No relation | Weak | Moderate | Strong | Extremely strong |
|---|---|---|---|---|---|
| Value | [0,0] | [0,1] | [1,2] | [2,3] | [3,4] |

The second step is to generate the interval direct-relation matrix. Pairwise relationships and influence levels between variables are transferred as a matrix, which is called the direct-relation matrix $Y$. Elements in the matrix $Y$ are interval numbers. If there are $N$ variables, then a direct-relation matrix with $N$ rows and $N$ columns is created and the individual item in the matrix is denoted by $Y_{ij}$, indicating the impact of ith variable on jth variable. The interval direct-relation matrix is expressed as follows:

$$Y = \begin{pmatrix} \begin{bmatrix} 0 & 0 \end{bmatrix} & \begin{bmatrix} a_{12}^{-} & a_{12}^{+} \end{bmatrix} & \cdots & \begin{bmatrix} a_{1n}^{-} & a_{1n}^{+} \end{bmatrix} \\ \begin{bmatrix} a_{21}^{-} & a_{21}^{+} \end{bmatrix} & \begin{bmatrix} 0 & 0 \end{bmatrix} & \vdots & \begin{bmatrix} a_{2n}^{-} & a_{2n}^{+} \end{bmatrix} \\ \vdots & \cdots & \begin{bmatrix} 0 & 0 \end{bmatrix} & \vdots \\ \begin{bmatrix} a_{n1}^{-} & a_{n2}^{+} \end{bmatrix} & \begin{bmatrix} a_{n2}^{-} & a_{n2}^{+} \end{bmatrix} & \cdots & \begin{bmatrix} 0 & 0 \end{bmatrix} \end{pmatrix}, \tag{5}$$

where $Y_{ij} = \left[a_{ij}^{-}, a_{ij}^{+}\right], a_{ij}^{-} \le a_{ij}^{+}$.

After the interval direct-relation matrix is obtained, the normalized crisp value $Y_{ij}$ can be acquired by Eqns (1) to (4) in previous section. The normalized direct relation matrix $X$ could be calculated by Eqns (6) and (7):

$$X = \lambda \times Y; \tag{6}$$

$$\lambda = \frac{1}{\max\limits_{1 \le i \le n}\left(\sum_{j=1}^{n} a_{ij}\right)}. \tag{7}$$

The third step is to calculate the total-relation matrix $T$ where $t_{ij}$ indicates the overall direct and indirect impacts of $i^{\text{th}}$ variable on $j^{\text{th}}$ variable:

$$T = \lim_{m \to \infty}\left(X + X^2 + X^3 + \cdots + X^m\right) = X\left(E - X\right)^{-1}. \tag{8}$$

In Eqn (8), $E$ is an identity matrix. The centrality degree and causal degree of each variable is calculated based on the total relation matrix. The sum of rows total matrix T is denoted as the influencing degree $D_i$, which refers to the total impacts of $i^{th}$ variable on all the other variables, as shown in Eqn (9). The influenced degree $R_j$ is calculated as the sum of column $j$, representing the total impacts of $j^{th}$ variable being affected by all the other variables (see Eqn (10)). The sum of the influencing degree and influenced degree ($D_i + R_j$) is defined as the centrality degree, which shows the importance level of this variable in the framework and its overall level being impacted and the impact to others. ($D_i - R_j$) is defined as the causal degree, indicating the difference level of the variable being impacted and the impact to others. A positive causal degree indicates it is a cause type variable and has stronger impacts on other variables than being impacted. A negative value means the variable is the relation type and significantly affected by other variables. The centrality degree and causal degree are calculated through Eqn (11). A causal diagram will be drawn using the centrality degree as the transverse and causal degree as the longitudinal axis.

$$D_i = \sum_{j=1}^{n} t_{ij},\ i = 1,2,\ldots,n; \quad (9)$$

$$R_j = \sum_{j=1}^{n} t_{ji},\ j = 1,2,\ldots,n; \quad (10)$$

$$P_k = D_k + R_k;\ E_k = D_k - R_k,\ k = i = j = 1,2,\ldots,n. \quad (11)$$

## 3. Determinants for the TAM-TOE BIM adoption model

### 3.1. Identify external variables

A total of twelve external variables of the BIM TAM-TOE model were identified from 21 existing studies, details can be seen in Table 3.

#### 3.1.1. Technical factors

Maturity and standardization level of the technology have significant impacts on companies' perceptions of new technologies. Three major technical factors of BIM adoption in previous studies are: localization, standardization and compatibility of BIM.

*Localization:* filling local users' needs and preference is important when introducing a new technology to a region or a country. BIM localization not only includes the localization of software operating environment, but also adaption to the features of local projects, such as the collaborative method, organizational form, and management process (Li, 2015). In China, BIM model which is compatible with the domestic construction industry has not yet been developed well.

*Standardization:* BIM standardization specifies the project stages, deliverables and goals to be achieved. Data exchange process, the content and format of deliverables are standardized for better information sharing and collaboration (Lee et al., 2013; Won et al., 2013; Li, 2015; Qin et al., 2016). Chinese governments have realized the importance of standardization in BIM implementation and have put some efforts on it. In June 2017, the Ministry of Housing and Urban-Rural Development of China officially approved the "Application Standard for Building Information Models (GB/T51235-2017)" and announced the implementation of it from January 1, 2018. Followed in October 2017, the "Classification and Coding Standards for Building Information Models (GB/T 51269-2017)" was officially approved and to be implemented from May 1, 2018. The national standard "Delivery Standards of Construction, Engineering and Design Information Models" was submitted for review in the same year, but it has not yet been officially released. The "Delivery Standard" will be applied with other standards to form a national BIM standard system and provide a basis for the coordination and docking of international BIM standards.

*Compatibility:* BIM application requires integration of multiple software, and only a unified data exchange standard could enable the data to be transmitted effectively (Hosseini et al., 2015). At present in China, there is usually limited interaction between BIM application between different companies due to the lack of a standard data interface. Software from different manufacturers has their own strengths in BIM applications, and there is a challenge to combine the advantages across them.

#### 3.1.2. Economic factors

Two economic factors are considered in relation to BIM adoption: the cost of applying BIM and the return on investment.

*Cost:* the application cost of BIM mainly includes: the cost of hardware equipment, the purchase and upgrade cost of software, the cost of personnel training, the consulting fee of hiring BIM consulting units and experts (Li, 2014). The TOE framework believes that the adoption of new technologies by organizations is primarily influenced by technology, organization and environment. However, organizations usually have stronger willingness in trying a lower cost technology due to lower risk of loss (Songer et al., 2001).

*Return on investment:* a new technology which brings quantifiable benefits could significantly offset relevant application costs. However, cost and benefit before and after the application of BIM is hard to capture and there are substantial intangible benefits of applying BIM technology, which adds more difficulties in calculating the return on investment (Cao et al., 2015).

#### 3.1.3. Organizational factors

Four organizational factors that influence the adoption of BIM technology were identified in the literature: organizational mode and workflow, traditional thinking mode, support from senior management, and the number of BIM experts and technicians.

*Organization mode and workflow:* the organizational mode and workflow of the construction industry are usually fixed, where each project stakeholder performs its own duties. It is difficult to change the building organi-

Table 3. A summary of literature on external variables in the BIM TAM-TOE model

| Category | Code | External Variables | References | | | | | | | | | | | | | | | | | | | | | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | |
| Technological Context | EV1 | Localization of BIM | | | | √ | | | | | | | | | | √ | √ | √ | √ | √ | | | √ | 7 |
| | EV2 | Standardization of BIM | √ | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | √ | 19 |
| | EV3 | Compatibility of BIM | √ | | √ | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | 19 |
| Economic Context | EV4 | Cost of using BIM | √ | √ | √ | | √ | √ | √ | | √ | √ | √ | | | √ | √ | | √ | √ | √ | √ | | 15 |
| | EV5 | Return on investment | | √ | | | | √ | √ | √ | | √ | | | | | | | √ | | | | √ | 7 |
| Organizational Context | EV6 | Organizational pattern and workflow | √ | √ | √ | | √ | √ | | √ | √ | √ | | √ | √ | √ | √ | | √ | √ | | | √ | 15 |
| | EV7 | Traditional thinking mode | √ | √ | | | √ | √ | √ | √ | √ | √ | | √ | | √ | | | √ | √ | | | √ | 13 |
| | EV8 | Executive support | √ | | √ | √ | √ | √ | | √ | | | √ | √ | √ | | √ | √ | √ | √ | | √ | √ | 15 |
| | EV9 | Number of BIM experts and technical staff | √ | √ | √ | | √ | | √ | | | √ | √ | | | √ | √ | | √ | √ | √ | | √ | 13 |
| Environmental Context | EV10 | Requirement from national policies | | √ | √ | | | | √ | √ | | | | | √ | | √ | √ | | √ | √ | √ | | 10 |
| | EV11 | Popularity of BIM in the industry | | √ | √ | √ | | | √ | √ | | √ | | √ | √ | | | √ | | √ | √ | √ | | 12 |
| | EV12 | Competitions from other companies | | | √ | √ | | | √ | | | | | √ | √ | | √ | √ | | | | √ | | 8 |

*Notes*:
A = Mehran (2016); B = Hosseini et al. (2015); C = Rogers et al. (2015); D = Ding et al. (2015); E = Chien et al. (2014); F = Eadie et al. (2014); G = HKCIC (2014); H = Zuhairi et al. (2014); I = Stanley and Thurnell (2014); J = Salleh and Phui Fung (2014); K = Xu et al. (2014); L = Lee et al. (2013); M = Won et al. (2013); N = Qin et al. (2016); O = Li (2015); P = Yang (2015); Q = Li (2014); R = Tian (2014); S = Xu (2015); T = Wang (2013); U = Construction Enterprise BIM Technology; Application Status Research Group (2015).

zational models and workflows, as well as the roles and work content within the organization, which hinders the application of BIM to some extent (Qin et al., 2016). BIM has limited advantages for existing organizational models and workflows in implementation, which usually involves process and organizational task changes in the integration (Gu & London, 2010; Arayici et al., 2011).

*Traditional thinking mode:* the inherent mode of thinking of professionals is often deep-rooted with accumulation of experience and proficiency. People tend to deal with problems in a way they are familiar with and are reluctant to change (Stanley & Thurnell, 2014; Qin et al., 2016). BIM, a revolution in the construction industry which reforms the coordination and communication between the participants of the project, is an innovative strike to the traditional thinking stakeholders.

*Support from management level:* top management commitment is one of the major success factors for adopting BIM technologies (Gilligan & Kunz, 2007). On one hand, corporate executives have a decisive role in BIM adoption (Lee et al., 2013). On the other hand, high-level officials play an important role in handling emerging issues associated with a new technology, such as changes in tasks and responsibilities and conflicts of interests (Shanghai Construction Industry Association & Shanghai Luban Consulting Company, 2014). Senior executives' understanding on the benefits and risks of the new technology is critical in implementing BIM.

*Number of BIM experts and technicians:* use of BIM requires professionals having relevant industrial experience and knowledge, and BIM application processes is designed by experts and technicians. Lack of technical talents is a prominent issue in China, where BIM development is still in its infancy (Shanghai Construction Industry Association & Shanghai Luban Consulting Company, 2014; Qin et al., 2016).

### 3.1.4. Environmental factors

Environmental factors reflect the perceptions and attitudes on BIM adoption at national, industrial and enterprise levels. Three major environmental factors have been identified in literature: national policy requirements, Popularity of BIM in the industry, and competition from similar companies.

*National policy requirements:* national policies have significant impacts on the development of information technology in the construction industry (Wang, 2013). For example, the British government has played an important role in promoting the application and the development of BIM (Eadie et al., 2014) and in recent years, the Chinese government has also published relevant policies to encourage BIM application.

*Popularity of BIM in the industry:* most of the companies are on the sidelines initially when the benefits of BIM adoption are not clear. With greater acceptance of BIM in the industry, the application of BIM is becoming a trend. Companies may follow up the trend even when they are not fully prepared for BIM.

*Competitions from other companies:* companies usually compete with each other in two ways: cost and differentiation. The differentiation strategy often leads to higher returns (Hosseini et al., 2015). If a company applies BIM before its competitors, it can differentiate and improve the competitiveness of the company and therefore likely to obtain more business opportunities. Companies which suffer huge competitive pressure from competitors will take immediate measures to eliminate the difference. In either case, competitions promote the application of BIM.

Table 4. Internal variables in the BIM TAM-TOE model

| Code | Variable | Definition |
|---|---|---|
| IV1 | Perceived ease of use | Potential ease and complexity of applying BIM for construction companies |
| IV2 | Perceived usefulness | Potential benefits from BIM for construction companies |
| IV3 | Intention to use | Construction companies' intention to use BIM |

### 3.2. Determine internal variables

This study used three internal variables taken from traditional TAM, including perceived ease of use, perceived usefulness and intention to use. Their definitions in BIM TAM-TOE model are given in Table 4.

### 3.3. Identify and calculate the relationships

Two methods have been applied to Figure out the influence relationships the 12 external variables and 3 internal variables in the BIM TAM-TOE model. One is referencing existing literature when sorting out the impacts between variables. The other is making reasonable assumptions based on theories and best judgements from professionals to identify all the potential relationships between the variables. Table 5 shows a summary of relationships, based on which a questionnaire regarding BIM adoptions in organizations was designed.

## 4. Analysis of the TAM-TOE BIM adoption model

### 4.1. Data collection and analysis

A questionnaire regarding BIM adoptions in companies is designed based on the TAM-TOE framework. The questionnaire is divided into three parts. The first section is the survey introduction, which briefs the purpose, purpose and explanation of the survey. The second part includes eight questions which investigate the background information of respondents. The background information mainly includes: the work unit, the highest education, the

Table 5. Potential relationships between variables

| Variables | EV1 | EV2 | EV3 | EV4 | EV5 | EV6 | EV7 | EV8 | EV9 | EV10 | EV11 | EV12 | IV1 | IV2 | IV3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EV1 | | | | ○ | | | | ○ | | | | | √ | | |
| EV2 | | | | ○ | | | | ○ | | | | | √ | √ | |
| EV3 | | | | ○ | | | | √ | | | | | √ | | |
| EV4 | | | | | | | | √ | | | ○ | | | | √ |
| EV5 | | | | | | | | √ | | | | | | √ | |
| EV6 | | | | | | | | | | | | | √ | | |
| EV7 | | | | ○ | | √ | | | ○ | | | | √ | | |
| EV8 | | | | | | √ | | | ○ | | | | √ | | |
| EV9 | | | | | | ○ | | | | | | | √ | | |
| EV10 | | ○ | | | | | | √ | √ | | √ | | √ | √ | √ |
| EV11 | | | | | | | | √ | √ | | | | ○ | √ | √ |
| EV12 | | | | | | | | √ | | | | | | √ | √ |
| IV1 | | | | | | | | | | | | | | √ | √ |
| IV2 | | | | | | | | | | | | | | | √ |
| IV3 | | | | | | | | | | | | | | | |

*Note:* in the above table, the symbol '√' indicates the correlations were identified from previous studies; '○' indicates the correlations were identified based on theories.

title, the working years, the management level, the number of BIM projects in the company, the number of BIM projects participated, and the implementer of the BIM project in the company. The first five questions collect the basic personal information and the last three questions are used to determine the BIM application status in respondents' companies and the BIM application experience of respondents. These questions ensure validity of the samples and allow the survey results to be classified and cross-analyzed. The third part is to collect respondents' judgments on the degree of influence between variables. In order to facilitate the judgements, the strength of the influence between each pair of variables is divided into five levels: no impact, weak influence, moderate influence, strong influence, and very strong influence.

As mentioned in Section 2.2, the interval number DEMATEL method is used for analysis which is based on the strength of the influence relationships between various factors. The quality of the questionnaire and the choice of the respondent sample determine the rationality of the data and the reliability of the conclusions. Therefore, all the questions were developed based on relationships between the factors identified in the past studies (as seen in Section 3.3). In addition, an open question "What other influence relationships do you think exist?" was included in the questionnaire in case of missing points. The questionnaires were only sent to technical staffs and managers with relevant BIM experience from development organizations, architecture companies, construction companies and consulting companies. And it was estimated that the minimum filling time for the questionnaire is about 200 seconds.

In order to facilitate the filling process and not subject to geographical restrictions, this questionnaire was distributed through "SO JUMP" (one of the leading Chinese online platforms for conducting surveys). The questionnaire was set as non-public to ensure that it was sent to the targeted groups (have used BIM or have related experience on BIM). The questionnaire collectors must send the QR code or the questionnaire address to the specific person and other people have no access to questionnaire. Invalid responses were excluded: (1) incomplete filling, important information is missing, or no BIM-related projects reported; (2) the answers follow a simple pattern, such as AAAA, ABCD or DCBA, which were considered as blind filling; and (3) filling time less than 200 seconds.

A total of 155 responses were received, of which the above three types of invalid questionnaires were excluded, and 120 remaining valid responses accounted for 77.4% of the total sample. The data obtained from the 120 questionnaires fully met the data requirements of the DEMATEL method (Tseng, 2009; Lee et al., 2010). A summary of the background of respondents is shown in Table 6.

The interval direct-relation matrix and crisp values were obtained through Eqns (1) to (5). As seen in Table 7, numbers in the square bracket [] are interval direct influence values and the number in the round bracket () are crisp values. The total relation matrix as shown in Table 8 was obtained through Eqns (6) to (8). In the total relation matrix, the numbers highlighted in yellow color are absent from direct-relation matrix and smaller than 0.1, indicating relevant low degrees of indirect relations between two variables. Using Eqns (9) to (11), the influencing degree, influenced degree, centrality degree and causal degree of each variable are calculated and shown in Table 9. From Table 9, four out of the total fifteen internal and external variables have influencing degrees higher than 0.6, which are Requirement from national policies (EV10), Popularity of BIM in the industry (EV11), Standardization of BIM (EV2) and Traditional thinking mode (EV7). Variables with high influenced degrees (>1.0) include: Perceived ease of use (IV1), Perceived usefulness (IV2) and Intention to use (IV3). Apart from the three internal variables, one external variable, the Executive support (EV8) also has a high influenced level. A pathway diagram which demonstrates the significant direct relationships between variables can be seen in Figure 4 with exclusion of all the highlighted values in Table 8.

### 4.2. Centrality degree and causal degree

Using the centrality degree (D + R) as the X axis, the causal degree (D – R) as the Y axis, the average central degree of the 15 variables (0.989) to draw the internal longitudinal axis and zero causal degree to draw the internal horizontal axis, variables were coordinated in the causal diagram in Figure 4. It could be seen that two variables with high centrality degrees: Requirements from national policies (EV10) and Popularity of BIM in the industry (EV11), are in quadrant one, which means that they are the core factors, thus should be listed as the priorities.

Table 6. Summary of descriptive background information of respondents ($N$ = 120)

| | | | | |
|---|---|---|---|---|
| 1) Organization | Development organization<br>18.33% | Architecture company<br>17.50% | Construction company<br>47.50% | Consulting company<br>16.67% |
| 2) Education | Diploma or below<br>4.17% | Bachelor<br>73.33% | Master<br>20.83% | PhD<br>1.67% |
| 3) Working experience | Less than 5 years<br>59.69% | 5 to 10 years<br>25.58% | 11 to 15 years<br>10.08% | 16 years or above<br>4.66% |
| 4) Number of BIM projects in the company | 1 to 3 projects<br>38.24% | 4 to 6 projects<br>38.98% | More than 6 projects<br>22.78% | |
| 5) Number of participated BIM projects | 1 to 2 projects<br>50.46% | 3 to 5 projects<br>35.24% | More than 5 projects<br>14.30% | |

Table 7. TAM-TOM direct-ration matrix and crisp value

| Influenced variables / Influencing variables | EV1 | EV2 | EV3 | EV4 | EV5 | EV6 | EV7 | EV8 | EV9 | EV10 | EV11 | EV12 | IV1 | IV2 | IV3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EV1 | | | | [1.362,2.224] (0.099) | | | | [1.421,2.351] (0.119) | | | | | [1.737,2.684] (0.150) | | |
| EV2 | | | | [1.807, 2.754] (0.131) | | | | [1.643, 2.572] (0.138) | | | | | [2.107, 3.089] (0.181) | [1.782, 2.691] (0.152) | |
| EV3 | | | | [1.825, 2.772] (0.132) | | | | [1.339, 2.232] (0.117) | | | | | [1.875, 2.839] (0.160) | | |
| EV4 | | | | | | | | [1.741, 2.704] (0.142) | | | [1.571, 2.482] (0.114) | | | | [1.600, 2.546] (0.142) |
| EV5 | | | | | | | | [1.768, 2.714] (0.128) | | | | | | [1.737, 2.684] (0.129) | |
| EV6 | | | | | | | | | | | | | [1.679, 2.589] (0.121) | | |
| EV7 | | | | [1.375, 2.304] (0.102) | | [1.649, 2.596] (0.137) | | | [1.465, 2.375] (0.111) | | | | [1.732, 2.715] (0.163) | | |
| EV8 | | | | | | [2.214, 3.197] (0.178) | | | [1.889, 2.870] (0.138) | | | | [2.055, 3.018] (0.189) | | |
| EV9 | | | | | | [1.807, 2.754] (0.131) | | | | | | | [1.927, 2.909] (0.156) | | |
| EV10 | | [2.155, 3.138] (0.156) | | | | | | [1.983, 2.966] (0.186) | [2.069, 3.051] (0.197) | | [2.138, 3.121] (0.157) | | [1.790, 2.720] (0.233) | [1.690, 2.604] (0.190) | [2.018, 2.964] (0.230) |
| EV11 | | | | | | | | [1.793, 2.776] (0.132) | [1.895, 2.877] (0.156) | | | | [1.604, 2.518] (0.163) | [1.690, 2.638] (0.143) | [1.875, 2.857] (0.181) |
| EV12 | | | | | | | | [2.088, 3.070] (0.151) | | | | | | [1.684, 2.632] (0.126) | [1.790, 2.772] (0.155) |
| IV1 | | | | | | | | | | | | | | [1.690, 2.604] (0.122) | [1.828, 2.810] (0.153) |
| IV2 | | | | | | | | | | | | | | | [2.190, 3.172] (0.158) |
| IV3 | | | | | | | | | | | | | | | |

Table 8. Total-relation matrix

| Influencing variables \ Influenced variables | EV1 | EV2 | EV3 | EV4 | EV5 | EV6 | EV7 | EV8 | EV9 | EV10 | EV11 | EV12 | IV1 | IV2 | IV3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EV1 | 0 | 0 | 0 | 0.099 | 0 | 0.021 | 0 | 0.119 | 0.018 | 0 | 0.011 | 0 | 0.150 | 0.020 | 0.036 |
| EV2 | 0 | 0 | 0 | 0.131 | 0 | 0.025 | 0 | 0.138 | 0.021 | 0 | 0.015 | 0 | 0.181 | 0.152 | 0.066 |
| EV3 | 0 | 0 | 0 | 0.132 | 0 | 0.021 | 0 | 0.117 | 0.018 | 0 | 0.015 | 0 | 0.160 | 0.021 | 0.042 |
| EV4 | 0 | 0 | 0 | 0 | 0 | 0.027 | 0 | 0.142 | 0.035 | 0 | 0.114 | 0 | 0.043 | 0.019 | 0.142 |
| EV5 | 0 | 0 | 0 | 0 | 0 | 0.023 | 0 | 0.128 | 0.018 | 0 | 0 | 0 | 0.024 | 0.129 | 0.024 |
| EV6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.121 | 0.015 | 0.019 |
| EV7 | 0 | 0 | 0 | 0.102 | 0 | 0.137 | 0 | 0.015 | 0.111 | 0 | 0.012 | 0 | 0.163 | 0.021 | 0.039 |
| EV8 | 0 | 0 | 0 | 0 | 0 | 0.178 | 0 | 0 | 0.138 | 0 | 0 | 0 | 0.189 | 0.023 | 0.029 |
| EV9 | 0 | 0 | 0 | 0 | 0 | 0.131 | 0 | 0 | 0 | 0 | 0 | 0 | 0.156 | 0.019 | 0.024 |
| EV10 | 0 | 0.156 | 0 | 0.020 | 0 | 0.056 | 0 | 0.186 | 0.197 | 0 | 0.157 | 0 | 0.233 | 0.190 | 0.230 |
| EV11 | 0 | 0 | 0 | 0 | 0 | 0.042 | 0 | 0.132 | 0.156 | 0 | 0 | 0 | 0.163 | 0.143 | 0.181 |
| EV12 | 0 | 0 | 0 | 0 | 0 | 0.027 | 0 | 0.151 | 0.021 | 0 | 0 | 0 | 0.029 | 0.126 | 0.155 |
| IV1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.122 | 0.153 |
| IV2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.158 |
| IV3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

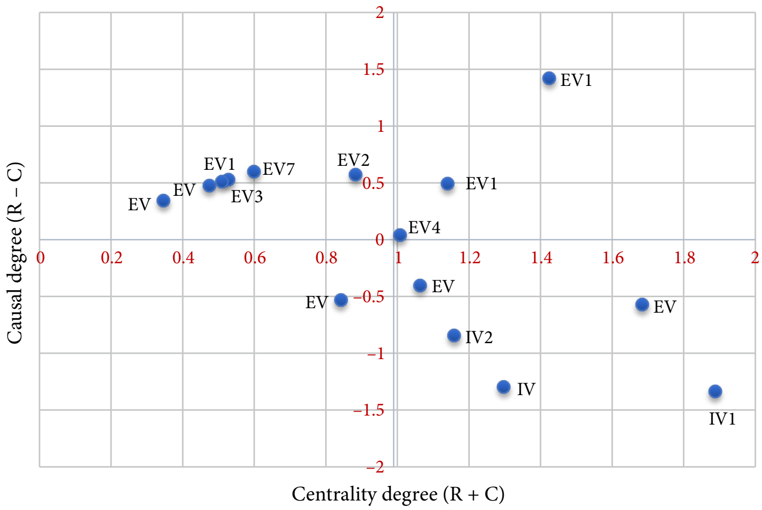


Figure 4. Scatter point diagram of centrality degrees and causal degrees of variables

In the meantime, the two variables having positive and high causal degrees, particularly EV10, are driving variables and have strong impacts on other variables.

The centrality degrees and causal degrees of variables could be further read with the pathways in Figure 4 in the above section. For example, cost of using BIM (EV4) falls into the first quadrant with a causal degree closing to 0, indicating that EV4 is impacted by other variables and has relative impacts on others. Cost is a key variable which strongly influences companies' applications of BIM. The companies could use other ways (change other variables) to reduce relevant cost. Figure 4 pathways indicate that cost can be reduced through technical strategies. Improving the Localization (EV1), Standardization (EV2) and Compatibility of BIM (EV3) can effectively cut the cost of BIM implementation.

Nearly a half of variables locate in quadrant two. If being ranked by their causal degree levels in descending order, these variables are Traditional thinking mode (EV7), Standardization (EV2) of BIM, Compatibility of BIM (EV3), Competitions from other companies (EV12), Localization of BIM (EV1) and Return on investment (EV5). In the meantime, these variables have high interaction influence level with other variables and thus belong to driving variables. From the influence pathways and values in Figure 4, the technical variables EV1, EV2 and EV3 greatly affect the Cost of using BIM (EV4), Executive support (EV8) and Perceived ease of use (IV1), and their impacts are mostly concentrated on the Perceived ease of use (IV1). Competitions from other companies (EV12) and Return on investment (EV5) directly impact on Perceived Usefulness (IV2).

Table 9. TAM-TOM causal influence level summarized table

| Code | Variable | Influencing degree (D) | Influenced degree (R) | Centrality degree (D + R) | Causal degree (D – R) |
|---|---|---|---|---|---|
| EV1 | Localization of BIM | 0.47 | 0.00 | 0.47 | 0.47 |
| EV2 | Standardization of BIM | 0.73 | 0.16 | 0.88 | 0.57 |
| EV3 | Compatibility of BIM | 0.53 | 0.00 | 0.53 | 0.53 |
| EV4 | Cost of using BIM | 0.52 | 0.48 | 1.01 | 0.04 |
| EV5 | Return on investment | 0.35 | 0.00 | 0.35 | 0.35 |
| EV6 | Organizational pattern and workflow | 0.15 | 0.69 | 0.84 | –0.53 |
| EV7 | Traditional thinking mode | 0.60 | 0.00 | 0.60 | 0.60 |
| EV8 | Executive support | 0.56 | 1.13 | 1.68 | –0.57 |
| EV9 | Number of BIM experts and technical staff | 0.33 | 0.73 | 1.06 | –0.40 |
| EV10 | Requirement from national policies | 1.42 | 0.00 | 1.42 | 1.42 |
| EV11 | Popularity of BIM in the industry | 0.82 | 0.32 | 1.14 | 0.49 |
| EV12 | Competitions from other companies | 0.51 | 0.00 | 0.51 | 0.51 |
| IV1 | Perceived ease of use | 0.28 | 1.61 | 1.89 | –1.34 |
| IV2 | Perceived usefulness | 0.16 | 1.00 | 1.16 | –0.84 |
| IV3 | Intention to use | 0.00 | 1.30 | 1.30 | –1.30 |

Only one variable: Organizational pattern and workflow (EV6), is in the third quadrant. It belongs to the relation type as it has a negative causal degree. Unlike the driving variables in quadrant one or two and effect variables in quadrant 4, EV6 is a less important variable due to its small centrality degree and weak relationships with other variables.

From Figure 5, Organizational pattern and workflow (EV6) can be treated as a transition variable since changes of Executive support (EV8), Traditional thinking mode (EV7) and Number of BIM experts and technical staff (EV9) will bring the changes of the workflow and patterns of the organizations. Therefore, extra attention and management is not required on EV6.

Variables in quadrant four have relatively high centrality degrees and negative causal degrees. These variables usually belong to relation or target variables. The five variables in quadrant four are: Executive support (EV8), Number of BIM experts and technical staff (EV9), Perceived ease of use (IV1), Perceived usefulness (IV2) and Intention to use (IV3). Among which the two external variables EV8 and EV9, which have high centrality degrees and are in the middle part of effect and cause diagram, are affected by the internal variables on the right side and driving variables on the left side. These two variables need to be controlled indirectly through other variables. From Figure 4, Requirements from national policies (EV10), Popularity of BIM in the industry (EV11), Localization of BIM (EV1), Standardization of BIM (EV2), Compatibility of BIM (EV3), Cost of using BIM (EV11), Return on investment (EV5) and Competitions from other companies (EV12) all have effects on Executive support (EV8) and Number of BIM experts and technical staff (EV9). It could be speculated that if companies provide time and financial supports for staff to learn BIM, professionals would be motivated and have greater passions and desires on learning and using BIM. Executive support (EV8) and Number of BIM experts and technical staff (EV9) have impacts on Perceived ease of use (IV1). Perceived ease of use (IV1) and Perceived usefulness (IV2) are internal variables and Intention to use (IV3) is the final target variable, the change of which can be monitored through observing changes of other internal variables.

## 5. Simulation analysis

From the calculation by the DEMATEL method in the above sections, influence paths and influence levels of the factors in the TAM-TOE model were obtained. Influence degree, influenced degree, centrality degree and causal degree of each variable were calculated. Eight factors were identified as driving factors, but it is not clear how their changes affect the targeting factor. To further understand the effect of the change of the cause factor (driving factor) on companies' intention to use BIM. This study used the eight driving variables (Localization of BIM (EV1), Standardization of BIM (EV2), Compatibility of BIM (EV3), Return on investment (EV5), Traditional thinking modes (EV7), Requirements from national policies (EV10) and Popularity of BIM in the industry (EV11)) with positive causal degrees as independent variables and Intention to use (IV3) as the dependent variables to run an interactive simulation. The variation of simulated target variables with value changes of the eight variables were captured through MATLAB software. The calculation steps are (Feng & Pi, 2013):

- Define an initial default value $I_0$, which describes the initial state of the system. For example, the default value can be set as $I_0$ = [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0] when studying impact of Localization of BIM (EV1) on Intention to use (IV3), in the vector, numbers are initial values of the 15 variables from EV1 to IV3.

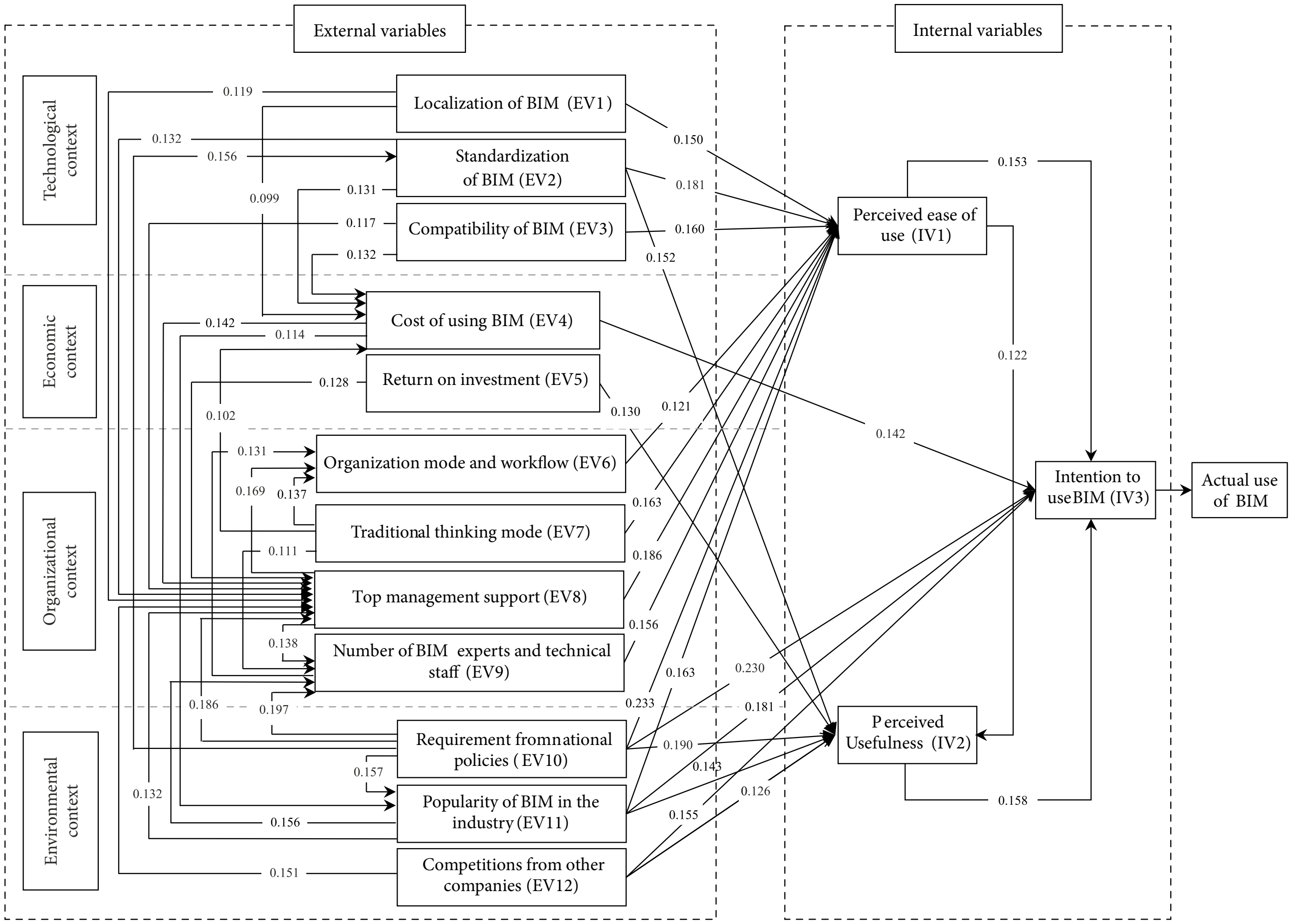


Figure 5. BIM Technology Acceptance Model based on TAM

- Determine the relation matrix $W$, which was the total relation matrix from DEMATEL.
- Iteration. Define the number of iterations to calculate $I_i$, through the Eqn (11):

$$I_i = I_{i-1} \times W + I_{i-1}, \; I_1 = I_0 \times W + I_0, \quad (11)$$

where $i$ is the number of iterations and $I_i$ is the value after $i^{\text{th}}$ iteration.
- Draw the iteration diagram and analyze the simulation results.

Ten iterations were set and the results of the ten simulations were summarized in Table 10. Figure 6 shows the linear relationships between variable IV3 and the other related 8 variables.

From Table 10 and Figure 6, the target variable Intention to use (IV3) significantly varied with changes of the eight driving variables. The eight drivers could be sorted and categorized according to associated change range and sensitivity of the target variable, and the results provide the basis for the companies to make targeted strategies and hierarchical management for BIM implementation. These variables can be divided into four levels according to the variation rates (as seen in Table 11): (1) Extremely rapid variation: The iterations of Requirements from national policies (EV10) can bring significant variation of IV3. The increasing rate is nearly four times of the simulations of other variables. (2) Rapid variation: Standardization of BIM (EV2) and Popularity of BIM in the industry (EV11) have significant and moderate impacts on IV3. (3) Moderate variation: IV3 changes slowly with iterations of the Compatibility of BIM (EV3), Traditional thinking modes (EV7), Standardization of BIM (EV1) and Competitions from other companies (EV12). (4) Slow variation: Returns on investment (EV5) has minor impact on IV3.

Recommendations on policies could be summarized according to the results. The significant and strong impact of Requirements from national policies (EV10) on Intention to use (IV3) indicates that the most effective way to promote applications of BIM technology in China are motivations measures of governments. Relevant policies could be developed to promote the standardization of BIM, encourage companies to use this technology, and then foster a type of BIM culture in the industry. Secondly, studies on the barriers of BIM implementation have suggested that the Return on investment (EV5) might be a key variable (see Table 3). However, this study found that the 'Returns from investment' has minor impact on a company's intention to use BIM. The possible reason is that the economic benefits from BIM have already been well recognized in the construction industry.

Table 10. Simulation results

| Simulation number / Independent Variable | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EV1 | 0.00 | 0.04 | 0.12 | 0.26 | 0.48 | 0.79 | 1.22 | 1.79 | 2.55 | 3.52 | 4.76 |
| EV2 | 0.00 | 0.07 | 0.21 | 0.45 | 0.79 | 1.28 | 1.93 | 2.79 | 3.88 | 5.27 | 7.01 |
| EV3 | 0.00 | 0.04 | 0.14 | 0.30 | 0.55 | 0.91 | 1.40 | 2.06 | 2.93 | 4.05 | 5.47 |
| EV5 | 0.00 | 0.02 | 0.08 | 0.16 | 0.29 | 0.48 | 0.73 | 1.06 | 1.48 | 2.02 | 2.69 |
| EV7 | 0.00 | 0.04 | 0.13 | 0.28 | 0.52 | 0.85 | 1.32 | 1.93 | 2.73 | 3.76 | 5.05 |
| EV10 | 0.00 | 0.23 | 0.58 | 1.08 | 1.80 | 2.78 | 4.09 | 5.82 | 8.06 | 10.93 | 14.56 |
| EV11 | 0.00 | 0.18 | 0.42 | 0.73 | 1.12 | 1.61 | 2.24 | 3.01 | 3.97 | 5.14 | 6.55 |
| EV12 | 0.00 | 0.16 | 0.34 | 0.56 | 0.83 | 1.16 | 1.56 | 2.05 | 2.64 | 3.37 | 4.25 |

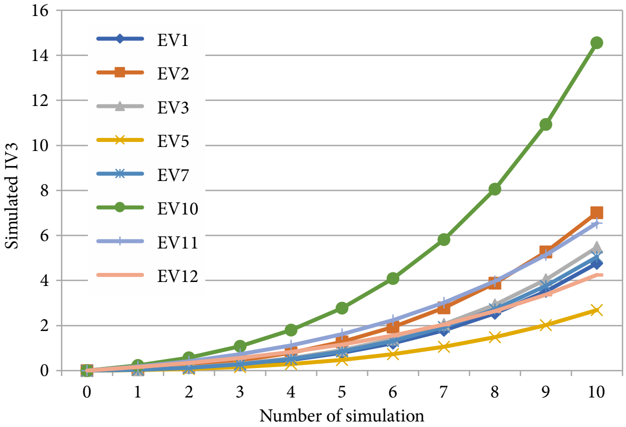


Figure 6. Simulated IV3 by the eight driving variables

## 6. Strategy analysis of BIM adoption

As seen in Table 11, there are three variables which have significant impacts on a company' intention to use. Since these three variables belong to environmental and technical categories, following discussion only focuses on the two dimensions.

### 6.1. Strategies on environmental factors

External environmental factors have the greatest impacts on the adoption intention, which are: Requirement from national policies (EV10) and Popularity of BIM in the industry (EV11)) and Competitions from other companies. As seen in Figure 7, the Requirement from national policies (EV10) has multiple long impact pathways. These pathways suggest that policies such as compulsory use of BIM in public projects and extra credits for projects with BIM technology in the bidding process, may promote implementations of BIM in the industry and create a better external environment for BIM application. Strengthening BIM culture in the industry will bring the standardization of BIM, at the same time, lower cost and policy incentives may attract greater executive support in the organizations. The innovation of organizational patterns and workflows will promote BIM implementation and there will be more BIM professionals in the industry. These changes will ultimately have great impact on companies' Perceived ease of use and Perceived usefulness of BIM technology and increase organization's willingness to use BIM.

(1) Enforcement of BIM application

In this case, because it is mandatory, the company does not consider ease of use and usefulness but directly adopts and applies it. It cuts off the influence of external variables on perceived ease of use and perceived usefulness, and enterprises are forced to accept BIM. According to the TAM-TOE model diagram, the influence path in this case is shown in Figure 8.

As seen in the above pathway, enforcement of BIM application will directly affect the company's intention to adopt and has the shortest route and is the most efficient in BIM promotion. Meanwhile, government intervention could set off the industry wave in BIM application. In United Kingdom, South Korea and Singapore, the government involvement has achieved expected results in a short period of time in BIM promotion.

Although this type of mandatory method is effective in BIM promotion, the actual value of BIM in practice could not be guaranteed. There is risk that BIM may be some time as the decorate of bidding documents rather than a tool actually being used, especially when the technology is not fully handled in the company. The United Kingdom, South Korea and Singapore have provided corresponding BIM application standards and other services while enforcing BIM implementation policies. China could learn the experience from these countries, however, what should be noticed is that unlike these countries which have smaller regional economic differences and are easier to take enforcement actions, China needs find a way to deal with the large-scale enforcement.

(2) Incentives in BIM application

In this case, the policy serves as an incentive tool. It acts as a policy factor that affects external variables, which in turn affects perceived usefulness and perceived ease of use, and ultimately affects the willingness of the company to adopt BIM. The influence path in this case is shown in Figure 7.

Table 11. Classification of the eight driving variables

| Level | Code | Variable | Group |
|---|---|---|---|
| 1 | EV10 | Requirement from national policies | Environmental Variable |
| 2 | EV2 | Standardization of BIM | Technical Variable |
| | EV11 | Popularity of BIM in the industry | Environmental Variable |
| 3 | EV3 | Compatibility of BIM | Technical Variable |
| | EV7 | Traditional thinking modes | Organizational Variable |
| | EV1 | Localization of BIM | Technical Variable |
| | EV12 | Competitions from other companies | Environmental variable |
| 4 | EV5 | Return on investment | Economic Variable |

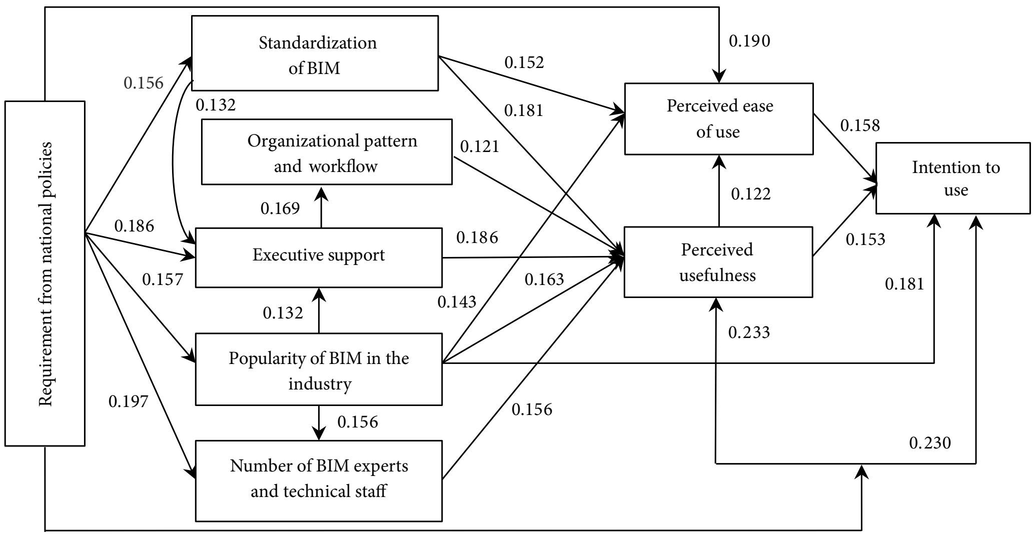


Figure 7. Influence pathways of government policies on BIM adoptions

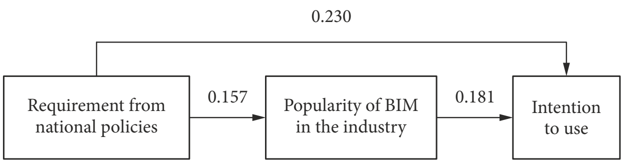


Figure 8. Influence pathways of BIM enforcement

The above two methods have advantages and disadvantages. Enforcement is efficient but is hard to control the effect while incentives may work well but slow in progress. In this regard, a three-stage measure in combination of the two methods proposed. In the first stage, BIM application could be enforced in pilot public projects. In this way, the BIM application process must be developed at the beginning, and the government participates in the application of the entire BIM as a construction unit and gradually establishes the BIM standards in the application process.

In the second stage, all medium-sized and large public projects are required to use BIM and private projects which voluntarily apply BIM should be rewarded, for example the tax incentives (overall low tax rate or industry-specific low tax rates or an R&D tax regime). At this time, BIM experts and technicians will gradually increase with growing number of BIM cases and projects. Relevant policies could be conducted to subsidize BIM research and education, foster the development of skilled professionals and enhance the confidence of enterprises in using BIM. In the third stage, some enterprises may still not adopt BIM while external conditions are mature. In this case, mandatory measures could be applied on projects exceeding certain amount of investment or occupying certain size of area.

## 6.2. Strategies on technical factors

The technical factors also have great impacts on the final adoption intention. The corresponding factors are Standardization of BIM (EV2), Compatibility of BIM (EV3) and Localization of BIM (EV1). Mature technical conditions are prerequisites for companies to adopt BIM, which requires not only software and hardware facilities but also standardization of BIM services. The BIM standardization provides guidance in BIM application and promotes information delivery and sharing during all stages of a project, such as investment planning, survey design, construction, operation and maintenance. The BIM standardization by government departments has two important functions: one is to show that the government supports BIM applications by actions; the other is to provide official and

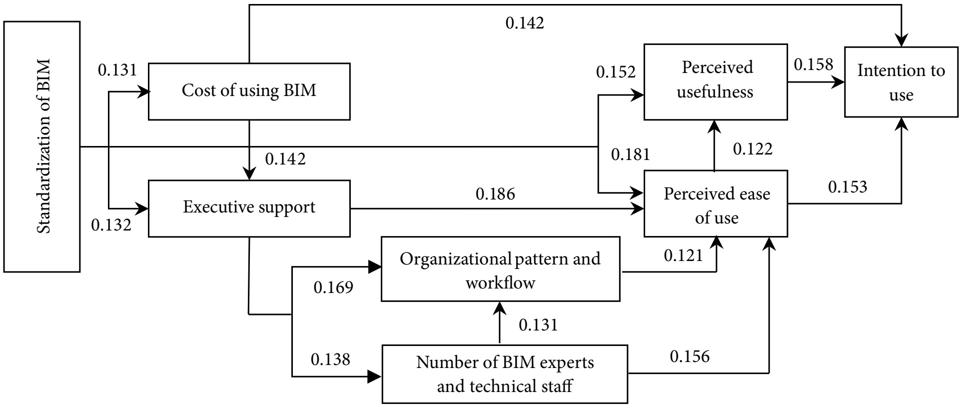


Figure 9. Influence Pathways of Standardization of BIM

credible guidance for compliance. Figure 9 shows the influence pathways and impact degrees of EV2 on Intention to use (EV3). Following the pathways, the standardization of BIM can reduce relevant cost of using BIM, gain more supports from management levels in the organization and finally increase the perceived usefulness. In addition, standardization of BIM will stimulate the improvement of organizational patterns and workflows. More experienced BIM professionals can reduce the difficulties of using BIM from technical aspect and thus increase companies' perceived ease of use. It can be concluded that 'Standardized criteria of BIM' is critical variable of BIM implementation in the industry and should be the focal efforts in the future.

In summary, the strategy on environmental factors is mainly to create external motivation for enterprises in BIM adoption by means of compulsory or encouraging. The strategy on technical factors is to provide convenience for enterprises in BIM application by developing localized products, formulating and perfecting BIM standards, and solving data compatibility issues.

## Conclusions and future work

There has been vast amount of studies on influential factors of BIM adoption, however, most of them focused on individual attitudes rather than organizational' acceptance. In consequence, this paper developed a TAM-TOE model for BIM acceptance based on the Technology Acceptance Model (TAM) and the Technology-Organization-Environment (TOM) framework, to investigate the factors influencing adoption of BIM by organizations rather than individuals. Key factors were identified for BIM adoption in organizations and strategic and policy implications for BIM application in construction organizations were suggested.

BIM has developed rapidly in China in the past few years due to the joint efforts of government departments and industries, however, the application and research of BIM is still in its infancy and below the expected level. For the construction industry-related enterprises, whether it is the passive promotion of industry development or the active need for survival, it is imperative to adopt and apply BIM. Therefore, if we can explore "what factors can affect the adoption of BIM by enterprises", it will effectively promote the application of BIM technology in China's construction industry and accelerate the pace of Informa ionization in the construction industry.

This study combined TAM and TOE and proposed a BIM TAM-TOE model. 12 external variables and the relationships among them were identified based on a comprehensive literature review. A questionnaire was designed based on the 12 external variables and 3 internal variables from the TAM-TOE framework and sent to development organizations, architecture companies, construction companies and consulting companies. A total of 120 responses were received. Based on the survey, influence levels between variables were obtained. An interval number DEMATEL method was used to calculate the influence degree, influenced degree, centrality degree and causal degree of each variable. By calculating the centrality and cause of each factor, the key factors affecting the adoption of BIM are obtained, an 'effect and cause diagram' was created based on the total relations between variables. Further sensitive simulation of important cause factors also provides a visual view of the change of the result factors accordingly. The major findings are summarized:

First, the Requirement from national policies (EV10) is the strongest driving variable. The others in descending orders are: Traditional thinking modes (EV7), Standardization of BIM (EV2), Compatibility of BIM (EV3), Competitions from other companies (EV12), Popularity of BIM in the industry (EV11), Localization of BIM and Return on investment (EV5). These causal variables can drive the changes of other variables and then impact on a company's intention to use BIM.

Second, the simulations and iterations of the eight driving variables revealed that the target variable Intention to use (IV3) varied significantly and is sensitive with changes of firstly, The Requirement from national policies (EV10), and then the Standardization of BIM (EV2).

The results indicate the important role of policy intervene in BIM adoptions in construction organizations. The paper recommended both enforcement and incentive strategies in promoting BIM application in China and suggested governments to mind the differences in economic environment and scale effects when learning the experience with other countries (such as UK and South Korea). A three-stage implementation of BIM was proposed: firstly, the government could encourage implementation of BIM in public projects and gradually establishes the BIM application standards in this process. In the second stage, the government could enforce of BIM application in medium-sized and large projects while rewarding private projects which voluntarily apply BIM. In this stage, investment could be focusing on research and development of BIM, such as researching and developing localized products, formulating and perfecting BIM standards, and solving data compatibility issues. In the third stage, mandatory measures could be applied on projects which exceed certain amount of investment or occupy certain size of area.

This study conducted an in-depth analysis of variables which have impact on the implementation of BIM in Chinese construction industry. However, relationships between these variables vary with the development of BIM technology, thus future research is needed to update the models and results to identify the key issues at different stages.

## Acknowledgement

This study is supported by the Fujian Soft Science Fund “BIM Adoption Model and Application Strategy Research of Construction Industry Enterprises Based on Industry Diffusion Characteristics” (2016R0062).

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