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# Practices and effectiveness of building information modeling in construction projects in China

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**Abstract:** Based on an investigation of 106 projects involving the use of building information modeling (BIM), this paper examines current BIM practices in China, and assesses how various practices alter their effectiveness. The results reveal that in current practice BIM is principally employed as a visualization tool, and how it is implemented is significantly associated with project characteristics. BIM use in the majority of the surveyed projects is seen to have positive outcomes, with the benefits of improved task effectiveness being more substantial than those related to efficiency improvement. The results also provide evidence that project characteristics significantly influence the success of BIM use; however, more substantial contributing factors to BIM effectiveness are the extent of integrated use and client/owner support. While indicating that current BIM practices involve both technological and organizational problems, the findings also provide insights into how the potential for BIM could be better exploited within the industry.

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1 **Keywords:** Building information modeling; Application area; Participant involvement;  
2 BIM effectiveness; Chinese construction industry

3

#### 4 **1. Introduction**

5 Performance problems such as cost overruns and schedule slippages have long plagued  
6 the construction industry and have prompted practitioners to explore new approaches in  
7 streamlining the design and construction process [1]. Particularly salient among these  
8 approaches in the past decade is the concept of building information modeling (BIM) [2,3].  
9 As a fundamentally new way of creating, sharing and utilising facility lifecycle data [4],  
10 BIM can be used in a number of areas such as clash detection, sustainability analysis, cost  
11 estimating, construction scheduling and offsite fabrication throughout the project lifecycle  
12 [5-7]. If used appropriately, BIM can facilitate a more integrated design and construction  
13 process and generate substantial benefits in terms of, for instance, fewer design  
14 coordination errors, more energy-efficient design solutions, faster cost estimation, reduced  
15 production cycle times and lower construction costs [4,8,9].

16 Despite its great potential, the advancement of BIM in the construction industry is still  
17 in a relatively infant stage, and the technology's actual diffusion rate among industry  
18 practitioners worldwide is still much lower than expected [10]. For those practitioners who  
19 have already been involved in BIM use, a relatively high percentage is still "just scratching  
20 the surface of how much value BIM can provide" [11]. While there are currently a variety  
21 of issues impeding the progress of BIM in the industry [12-15], one of the most effective  
22 facilitating manoeuvres lies in eliciting experiences and lessons from current BIM practices

1 to provide momentum and insights for the future [7,8,16].

2       Based on an investigation of 106 recent projects involving the use of BIM, this study  
3 aims to provide an overview of current BIM practices in the Chinese construction industry,  
4 and gain insights into how these practices differ from each other in their effectiveness. In  
5 outlining current practices, two specific BIM issues are particularly examined: (1) areas  
6 where BIM is currently applied in the design and construction stages; and (2) the roles of  
7 project participants. Quantitative analyses are then performed to examine whether and how  
8 these practices are associated with related project attributes. In order to provide further  
9 comparisons of the practices involved, a quantitative assessment is also made of how BIM  
10 practice characteristics, together with related project attributes, influence the perceived  
11 effectiveness of BIM use in different project contexts.

12       The rest of the paper is organized as follows. The next section presents the research  
13 background, including a review of literature related to BIM practices and effectiveness.  
14 Section 3 outlines the research method, and section 4 presents the analyses of the survey  
15 and interview data. Section 5 discusses the research findings and implications. Section 6  
16 concludes the paper.

17

## 18 **2. Research background**

19       The concept of BIM can be traced back to the working prototype “building description  
20 systems” proposed by Eastman in the mid 1970s [17]. Due to its great potential benefits but  
21 still relatively limited application in practice, BIM has become a highly active research  
22 topic in recent years [3,18]. The vast majority of studies have focused primarily on

1 technical issues, including exploring potential areas in which BIM could be beneficially  
2 used [19-26] and enhancing interoperability among different modeling tools [27-30]. The  
3 purposes of these studies mainly relate to validating or improving the technical feasibility  
4 of related BIM prototypes, including the further integration of these prototypes with other  
5 technologies such as laser scanning and radio frequency identification (RFID).

6 In view of the possible gap between technical feasibility and practical adoption, there  
7 is an increasing research effort to examine empirically how BIM is currently used in design  
8 and construction activities [12,31-33]. To date, most of these investigations have been  
9 conducted in the form of case studies of individual construction projects, and in particular  
10 those in North America and Europe which are at the forefront of BIM deployment in the  
11 industry [31-33]. Through examining the detailed processes of BIM use in specific projects,  
12 these case studies are valuable in providing professionals with an in-depth understanding of  
13 concrete project benefits and possible obstacles to using BIM in specific project contexts  
14 [34]. However, activities in a single project can only characterise one aspect of industry  
15 practices, and it is often difficult to generalise practitioners' *ad hoc* experiences in single  
16 case projects [7,35]. As examples of BIM practices across the industry accumulate, there is  
17 a strong need for further research to statistically synthesise the anecdotal evidence from  
18 different project contexts and, therefore, provide industry practitioners with a more  
19 generalised understanding of how BIM could be used more effectively in the design and  
20 construction process [15,36].

21 The value and effectiveness of BIM have also attracted increasing scholarly interest in  
22 recent years. Drawing on secondary data from academic and practitioner sources, Bryde *et*

1 *al.* [8] qualitatively assess how the use of BIM could influence the key success criteria  
2 related to project outputs. Giel and Issa [9] and Barlish and Sullivan [37] conduct case  
3 studies to quantitatively examine the value of BIM, finding that the calculated returns on  
4 investment (ROI) vary greatly between projects. These studies collectively suggest that  
5 many of the project benefits brought about by BIM are actually qualitative or relatively  
6 intangible [9,37]. Even for such quantitative benefits as reduced change orders and fewer  
7 requests for information (RFIs), the related quantification process is still quite challenging  
8 as a large amount of information needs to be accurately recorded and extremely similar  
9 projects without BIM need to be available for necessary comparisons [8,37,38]. Moreover,  
10 as separate projects generally use BIM for different project benefits, it is not always  
11 appropriate to rank project practice success based solely on comparing absolute benefit  
12 values [4,5]. In order to structurally compare the effectiveness of BIM practices in different  
13 projects and draw conclusions on how they are influenced by related BIM use  
14 characteristics and project attributes, this study focuses on examining three perceived  
15 effectiveness variables: BIM-based task efficiency improvement, BIM-based task  
16 effectiveness improvement, and overall BIM success. The conceptual research model of  
17 this study is shown in Fig. 1.

18 < Insert Fig. 1 here >

19

### 20 **3. Research method**

#### 21 **3.1. Survey instrument**

22 This study is part of an industry-wide investigation to assess the state of BIM adoption

1 and implementation practices in the Chinese construction industry. With its intrinsic  
2 advantage of allowing replicability and thus enabling structured comparisons across  
3 different projects, a questionnaire survey was used as the main method of collecting  
4 project-based data. Following Eisenhardt [39], a mix of other data collection methods,  
5 including interviews, direct observation and document analysis, was also used in order to  
6 better design the survey and to gain more detailed information relating to the surveyed  
7 projects.

8 As the starting point, an exploratory investigation was carried out to gain a preliminary  
9 understanding of current BIM use practices in China. This included semi-structured  
10 interviews with related industry professionals from organizations that have pioneered BIM  
11 use, the first author's 3-month ethnographic observation of an industrial project in  
12 Shanghai, and the researchers' short observations and document analysis of several other  
13 projects. Based on information gleaned from these interviews and observations as well as  
14 related literature, a draft of the survey questionnaire was developed to collect project-based  
15 data on BIM-related practices. The questionnaire was then sent to 23 respondents to  
16 conduct a pilot study, with the aim of assessing the appropriateness of the questionnaire  
17 scope, identifying ambiguous expressions and testing the validity of related constructs.  
18 Based on respondents' feedback, the questionnaire was further revised and subsequently  
19 distributed to targeted construction projects.

20 The questionnaire associated with this study was structured into four sections. The first  
21 section concentrates on general information of the surveyed project. The second section  
22 evaluates the extent to which BIM has been used in different application areas. The third

1 section focuses on the roles of the key project participants involved. In the last section,  
2 respondents are asked for their perceptions of the effectiveness of BIM usage in the  
3 surveyed projects.

4

### 5 **3.2. Sampling and data collection**

6 Only Chinese mainland construction projects using BIM were considered. Since the  
7 use of BIM is still relatively rare in China, a completely random sampling method could  
8 not be used to elicit cases from a specific project database. Instead, a wide variety of  
9 different kinds of typical BIM projects and appropriate project respondents were identified  
10 by several methods, including searching through related industry publications, interviewing  
11 pioneering corporations in BIM utilisation, requesting information from industry  
12 associations, and contacting professionals participating in three BIM industry seminars held  
13 by Tongji University between 2009 and 2011. Targeted project respondents were identified  
14 as those most-informed senior and professional individuals directly involved in the use of  
15 BIM. A snowball sampling technique [40] was also utilised to increase the sample size,  
16 with the initially contacted respondents being asked to share related information concerning  
17 knowledgeable participants of other BIM-based projects. A diversified set of projects with  
18 different geographic locations and project types was selected to improve the  
19 representativeness of the sample and thus provide the best possible view of current industry  
20 practice.

21 Responses were collected by a variety of means including e-mail, personal visits and  
22 an online survey system. To those survey recipients expected to return their questionnaires



1 through e-mail or online survey system, reminder emails or telephone calls were sent three  
2 weeks after the first contact. After an almost 14-month investigation from November 2012  
3 to January 2014, a total of 137 responses from 125 projects were obtained. After  
4 completing the questionnaires, some respondents were also contacted to allow further  
5 interpretation of their answers and to provide more details of the surveyed projects.  
6 Whenever possible, respondents were also requested to share possible project documents  
7 including BIM usage plans, animations of BIM models and any other materials that could  
8 help the researchers understand the BIM practices involved in the surveyed projects. The  
9 completed questionnaires were then carefully scrutinised and coded based on follow-up  
10 contacts and supplementary documents. For projects with more than one response, the  
11 Interclass Correlation Coefficient (ICC) was calculated in order to assess inter-rater  
12 agreement [41]. This showed most of the items involved in the study to have ICC values  
13 larger than the criteria of 0.6, indicating inter-rater agreement. In cases where there was a  
14 difference, the corresponding respondents were further contacted to clarify the rationale  
15 underlying their answers and the response considered to contain the most reliable answers  
16 was selected for each project case. After the further omission of responses due to either  
17 incomplete information concerning key variables or due to projects being in the early  
18 design stage, 106 project cases were ultimately included in the analysis. The demographics  
19 of these projects are shown in Table 1.

20 < Insert Table 1 here >

21 Among the 106 project-specific responses, 47.2% were collected through e-mail, with  
22 the remaining 37.7% and 15.1% collected by personal visits and the online survey system

1 respectively. An analysis of variance (ANOVA) was conducted to compare the answers  
2 from the three types of responses, and no statistically significant differences were identified.  
3 The respondents were from a mix of project participants, with 13.2% from clients/owners,  
4 34.9% from designers, 32.1% from general contractors (including EPC/DB contractors),  
5 15.0% from consultants and 4.7% from subcontractors. Most respondents were senior and  
6 professional individuals knowledgeable of BIM use, with 29.2% being project managers or  
7 chief project engineers, 17.9% BIM managers, 24.5% BIM engineers, and the remaining  
8 28.3% being other types of engineers also directly involved in the use of BIM.

9

### 10 **3.3. Measurements and construct validity**

11 The questionnaire items used to measure BIM practices and effectiveness were  
12 developed based on information collected from the literature and industry practice. The  
13 classification of detailed BIM application areas was based principally on a comprehensive  
14 review of the frameworks provided by Eastman *et al.* [4], CICRP [5], Hartmann *et al.* [7]  
15 and Gao and Fischer [35] and the results of preliminary interviews and project observations.  
16 After further revisions based on the pilot study feedback, a total of 13 BIM application  
17 areas were finally incorporated into the questionnaire [42] (see Table 2). As the list of  
18 application areas is not exhaustive, two open-ended items (one for the design stage and the  
19 other for the construction stage) were also included in the questionnaire for respondents to  
20 indicate other areas in which BIM was being used in their projects. The extent of BIM use  
21 in each application area was measured on a three-point scale of "0" (not used), "1" (some  
22 use) and "2" (extensive use). To avoid misleading respondents into providing information

1 with which they were not familiar, an alternative “not clear” option was also provided.

2 < Insert Table 2 here >

3 The roles of the key project participants (including the client/owner, designer, general  
4 contractor, subcontractors and consultants) were further examined within the questionnaire.  
5 As suggested by Gao and Fischer [35], the roles were classified into three categories of:  
6 “leading” (i.e., coordinating the whole process of creating, reviewing and utilising BIM  
7 models), “participating” (i.e., involved in but not leading the BIM process) and “not  
8 involved”. The respondents were also asked to identify whether the majority of BIM costs  
9 in the surveyed projects were passed on to clients/owners. Due to the client/owner’s special  
10 influence in project design and construction activities [55,56], the level of client/owner  
11 support (COS) of BIM use in each surveyed project was further examined through three  
12 measurement items adapted from the measures of leadership involvement validated by Zhu  
13 *et al.* [57].

14 The three effectiveness variables, i.e., BIM-based task efficiency improvement (TEY),  
15 BIM-based task effectiveness improvement (TES) and overall BIM success (OBS), were  
16 operationalised as reflective constructs with multiple items (see Table 3). The items of TEY  
17 and OBS were primarily adapted from Gattiker and Goodhue [58] and Hung *et al.* [59], and  
18 were reworded to suit the context of BIM adoption in construction projects. The items of  
19 TES were developed based on Hoegl and Gemuenden [60] and Gao and Fischer [35]. The  
20 items of these constructs are shown in Table 3. These items were all rated on a seven-point  
21 Likert scale of "1" (strongly disagree) to "7" (strongly agree).

22 < Insert Table 3 here >

1 The levels of COS, TEY, TES and OBS are represented by the averages of the  
2 respondents' self-reported scores of respective items, with higher values of the averages  
3 indicating higher levels of support or effectiveness. As reported in Table 4, all four  
4 constructs have a composite reliability in excess of the threshold value of 0.70, implying  
5 acceptable levels of instrument reliability [61]. It is also shown that the square roots of the  
6 average variance extracted (values on the diagonal of the correlation matrix in Table 4) are  
7 all greater than the absolute value of inter-construct correlations (off-diagonal values),  
8 suggesting that the constructs possess good discriminant and convergent validity.

9 < Insert Table 4 here >

10

## 11 **4. Analyses and results**

### 12 **4.1. Application areas**

13 The state of the surveyed projects' BIM practices in different application areas is  
14 illustrated in Fig. 2, showing that there are varying degrees of frequency. The most  
15 frequently used application areas are clash detection in the construction stage (83.96%) and  
16 3D presentation in the design stage (76.42%). These are followed by construction system  
17 design (75.47%), design coordination (66.04%) and design option analysis (63.21%). Site  
18 analysis and site resource management are the two least-frequent application areas. Only a  
19 small minority of the surveyed projects attempted to use other non-listed application areas  
20 in the design (5.66%) and construction (3.77%) stages. These areas include checking the  
21 design against building codes, controlling construction safety, and checking construction  
22 quality based on laser scanning technologies.

1 < Insert Fig. 2 here >

2 From Fig. 2, it is evident that the depth of BIM use in most application areas is still  
3 relatively limited. Except in 3D presentation and clash detection, the use of BIM in all  
4 other areas is identified as “some use” more often than “extensive use”. Overall, the survey  
5 results indicate that, while the majority of the surveyed projects have attempted to use BIM  
6 across several application areas, in-depth use in most projects is limited principally in the  
7 area of visualization. Further examination of the results indicates that BIM use in 31.13%  
8 of the surveyed projects was restricted to a single project stage, with 11.32% and 19.81% of  
9 projects limiting BIM use within the design and construction stages respectively. Another  
10 noteworthy observation is the greater use of BIM in quantity take-offs in the construction  
11 stage than in cost estimation at the design stage, although related research has claimed that  
12 earlier utilisation of BIM in the design stage could generate much greater benefits in  
13 project cost controlling [4,46].

14 In order to examine the relationship between project attributes and BIM use practices,  
15 a principal component analysis (PCA) was performed to aggregate the BIM usage in the 13  
16 application areas into one summated factor, and the factor scores then used as dependent  
17 variable values to perform three separate linear regressions on the influences of project size,  
18 project type and project nature. A test for internal consistency of the summated factor,  
19 which is used to measure the extent of BIM use as a whole in each project, yields a  
20 satisfactory Cronbach’s Alpha of 0.805. As shown in Table 5, project size and project type  
21 are both significant predictors of the extent of project BIM use. The influence of project  
22 nature on the other hand is not found to be significant. Follow-up contact and further

1 examination of the survey data indicate that, even though government-investment projects  
2 generally possess more resources to invest in innovative technologies, in many public  
3 projects BIM is still deployed primarily as a visualization tool, especially in stadium and  
4 exhibition hall projects due to their specific needs to represent complex designs to the  
5 public and non-professional clients/owners.

6 < Insert Table 5 here >

7

#### 8 **4.2. Participant involvement and client/owner support**

9 The roles of key project participants in the use of BIM are profiled in Table 6. It is  
10 evident that general contractors and designers are those most frequently involved, with  
11 percentages of 83.02% and 76.42% respectively. In nearly half (40.57%) of the projects,  
12 designers are identified as the leading participants in creating, reviewing and using BIM  
13 models. It is significant to note that BIM consultants are also involved in using BIM in  
14 approximately one third of the surveyed projects, mostly acting as BIM converters of the  
15 traditional two-dimensional (2D) project documentation produced by designers. This result  
16 is unsurprising as BIM is still a relatively new solution for many industry practitioners in  
17 China, and a number of BIM consulting entities have emerged in recent years, either from  
18 traditional construction management consultants or newly established by pioneering BIM  
19 professionals.

20 < Insert Table 6 here >

21 While there are increasing project participants involved in BIM use, it seems that few  
22 project teams work collaboratively to share a BIM model throughout the project lifecycle.

1 In most cases, each participant builds their own BIM model to suit the specific needs of  
2 their own disciplines, and as a result, several respondents indicated mistrust and  
3 collaboration issues among participants in their projects. A contractor in one of the leading  
4 skyscraper projects in China involving BIM use also commented:

5 *(The designers) do not trust our (BIM) models, neither do we trust theirs ... The BIM*  
6 *models provided by the designers are quite inconsistent with their later provided (2D) shop*  
7 *drawings. Frankly speaking, (our own BIM) model is almost rebuilt by ourselves. We have*  
8 *only referred to the axes and elevations in their models.*

9 Respondents in around half of the surveyed projects (50.94%) revealed that BIM costs  
10 in their projects have been passed on to the clients/owners. Some of the respondents,  
11 however, further indicated that while some project clients/owners allow the inclusion of  
12 BIM costs in bidding prices, such costs are often suppressed to extraordinarily low levels,  
13 which can be an important cause of problems later encountered in BIM use practices in  
14 their projects. To further understand the client/owner's roles in BIM use, the respondents  
15 were also asked to rate their perceptions of the clients/owners' level of overall support,  
16 which was measured in three dimensions comprising the allocation of sufficient resources,  
17 ranking BIM use as a priority and actively driving project participants to use BIM  
18 collaboratively. A one-way ANOVA was then performed to assess the mean differences of  
19 COS across different kinds of projects. As shown in Table 7, there is a general trend for  
20 clients/owners to provide more support for BIM use with larger, non-residential and public  
21 projects.

22 < Insert Table 7 here >

1 Table 7 shows that the mean score of COS in the surveyed projects is 4.12 (SD = 1.41),  
2 which is quite neutral for a seven-point Likert scale. This result suggests that while  
3 considering clients/owners' behaviours in the aspects of championing BIM as well as  
4 driving project teams to adjust project processes and reassign organizational responsibilities,  
5 their overall support of BIM use is still relatively lacking. This is also corroborated by  
6 follow-up contact, in which several respondents indicated that after the use of BIM, related  
7 contract clauses and responsibility allocation have not actually changed in their projects.  
8 One contractor in an exhibition hall project described that the only obvious change in their  
9 project may be the addition of a new department to build BIM models. It seems that such  
10 limited process and organizational change may be not only due to clients/owners' lack of  
11 knowledge on the effectiveness of BIM use, but also from the resistance to change, as the  
12 client/owner in a large-scale public project in Shanghai commented:

13 *(We) have no intentions to change related project participants' responsibilities just*  
14 *because of the use of BIM ... we do not want to change the behaviours of the majority (of*  
15 *the project participants), because such a change may influence the progress of our project*  
16 *to some extent.*

17

### 18 **4.3. BIM effectiveness and its association with BIM usage characteristics**

19 The respondents' perceived effectiveness of BIM is partly presented in Table 8, with  
20 the relatively positive results in task efficiency improvement (mean = 4.89, SD = 1.22),  
21 task effectiveness improvement (mean = 5.32, SD = 0.91) and overall BIM success (mean  
22 = 5.00, SD = 0.92). Specifically, only 17.92% of the surveyed projects have OBS mean



1 scores not exceeding the threshold value of 4, indicating the use of BIM to have positive  
2 outcomes in the majority of the projects. A paired-samples t-test indicates the mean score of  
3 TES to be statistically higher than that of TEY ( $t = 3.50$ ,  $p < 0.001$ ), suggesting that BIM  
4 has brought about more benefits in advancing project task quality than in improving design  
5 and construction productivity.

6 < Insert Table 8 here >

7 A one-way ANOVA was performed to examine whether the project stage involved  
8 influences the effectiveness of BIM use. Compared with its use solely in either the design  
9 or construction stage, as illustrated in Table 8, the integrated use of BIM across both design  
10 and construction stages results in significantly better performances in the TEY, TES and  
11 OBS. Also of note is that the TEY mean (3.83) for BIM use solely in the design stage is  
12 below the threshold value of 4, indicating that limited BIM use may not necessarily lead to  
13 higher efficiency in design activities. As a designer in a hotel project commented:

14 *The interface of (the modeling software we are using) is relatively complex, especially*  
15 *for we 'green hands' ... the development of 'component families' for (the modeling software)*  
16 *in the industry are still at a early stage, and using this software generally involves more*  
17 *time in carrying out design tasks ... in those projects with tight design schedules, it is*  
18 *generally preferable for us to use 'traditional' 2D CAD tools instead.*

19 In order to further understand how higher levels of integration contribute to improving  
20 BIM effectiveness, hierarchical regression analysis was used to test the relationships  
21 between BIM practice characteristics and effectiveness variables. This enables the  
22 incremental effects of BIM use extent and client/owner support to be examined by

1 controlling for the effects of project attributes. A total of three separate hierarchical  
2 regressions were performed, which employed TEY, TES and OBS as their dependent  
3 variables respectively. For each of these regressions, the blocks of independent variables  
4 were entered individually, starting with control variables (model 1), then the extent of BIM  
5 use (model 2), and finally client/owner support (model 3). The results of these regressions  
6 are presented in Table 9.

7 < Insert Table 9 here >

8 Table 9 shows that the effects of project attributes account for significant, or nearly  
9 significant, amounts of variances both in TEY ( $R^2 = 0.165$ ,  $p < 0.001$ ) and in OBS ( $R^2 =$   
10  $0.075$ ,  $p < 0.075$ ), and that project size, specifically, has a significant positive influence on  
11 these two effectiveness variables. More substantial impacts on BIM effectiveness, however,  
12 originate from related BIM practice characteristics. After controlling for the effects of  
13 project attributes, the inclusion of the extent of BIM use results in highly significant  
14 changes in  $R^2$  for the three effectiveness variables of TEY ( $\Delta R^2 = 0.098$ ,  $p < 0.001$ ), TES  
15 ( $\Delta R^2 = 0.111$ ,  $p < 0.001$ ) and OBS ( $\Delta R^2 = 0.228$ ,  $p < 0.001$ ). These results provide strong  
16 evidence that more comprehensive use of BIM could contribute to greater improvements in  
17 task efficiency, task effectiveness and overall BIM success. The further inclusion of a  
18 client/owner support variable does not significantly increase  $R^2$  for TEY, but its influences  
19 on both TES ( $\Delta R^2 = 0.067$ ,  $p < 0.01$ ) and OBS ( $\Delta R^2 = 0.036$ ,  $p < 0.05$ ) are significant.

20

## 21 **5. Discussions and implications**

22 While government agencies in several countries (e.g., Singapore, South Korea, the UK,

1 and the USA) have already established plans for the mandatory use of BIM for public  
2 projects, the Chinese government has not yet issued any nationwide regulations to mandate  
3 BIM deployment and, therefore, the evolution of BIM practices in China has primarily  
4 been regulated by the marketplace during the past decade. Compared with early practices  
5 (specifically in those projects built for the 2008 Beijing Olympic Games around 2004) in  
6 which BIM was predominantly used to visualize complex facility shapes during the  
7 architectural design stage, a distinct characteristic of BIM practices in the surveyed projects  
8 of the present study is that BIM use has been frequently extended to application areas  
9 within the construction stage. Such a change seems to be relatively inspiring as some recent  
10 investigations, such as Eadie et al.'s survey in the UK in 2012 [12] and the SmartMarket  
11 survey in Western Europe in 2010 [62], show that in some developed countries contractors  
12 are still significantly less frequently involved in BIM use than designers, and many BIM  
13 practices are still limited to the design stage. Such a change also seems to be similar with  
14 what has happened in North America, where BIM has been increasingly used during the  
15 construction stage [63] and the BIM adoption rate among contractors is reported to have  
16 surpassed that of designers [64]. There are several reasons for this change. As it is required  
17 to submit 2D project documentation for regulatory approvals but it is still difficult for BIM  
18 software applications to automatically generate 2D shop drawings in accordance with  
19 industry specifications in China, BIM use is often regarded as extra work by the designers  
20 with fixed fee contracts. As for contractors within the highly fierce competition  
21 environment of the construction market, however, they often have internal incentives to  
22 actively embrace innovative technologies such as BIM to effectively manage construction

1 activities or to win more construction contracts. As a result, several large-sized contractors,  
2 such as the China State Construction Engineering Corporation, have already established  
3 corporation-wide mechanisms of staff training and project awards to facilitate the diffusion  
4 of BIM in their subsidiaries.

5 Despite these clear developments, the overall adoption rate of BIM in China remains  
6 considerably lower than that of pioneering countries [10,11,64]. It is also evident in the  
7 surveyed projects that the in-depth use of BIM to date is still limited principally to the areas  
8 of visualization, with the aim of visually conceptualising the form of complex facilities or  
9 virtually detecting the conflicts of building systems. This corresponds with a number of  
10 previous investigations in which BIM is also identified to be most frequently used as a  
11 visualization tool in many other countries [7,65,66]. This can be attributed partly to the  
12 continued persistence of data interoperability problems among various BIM applications  
13 that require relatively specific and different data models, and to the tedium involved in  
14 importing information from previously created 3D models to related performance analysis  
15 applications that are customised to industry specifications in China. Also, the traditional  
16 modular view of BIM application areas has resulted in many projects only trialling the use  
17 of BIM in some application areas, with the purposes of training professional staff,  
18 exploring suitable BIM process, and guiding the BIM use in future projects.

19 While collaboration problems related to integrated BIM use have been reported in  
20 many countries [11,14,67], such problems caused by the use of traditional project delivery  
21 systems seem to be particularly severe in China at present. According to Becerik-Gerber  
22 and Rice's survey in the US construction industry in 2009 [68], the majority of BIM-based

1 construction projects were being delivered through relatively collaborative methods such as  
2 integrated project delivery (IPD) and design-build (DB) to better leverage BIM benefits,  
3 and only 32.7% were being delivered through the traditional design-bid-build (DBB)  
4 system. Limited by a number of regulations on the project execution processes and related  
5 bidding mechanisms in the Chinese construction industry, however, design and  
6 construction services in most Chinese mainland construction projects are procured  
7 separately through the traditional DBB method. Such a situation has not changed markedly  
8 with the advent of BIM in the industry. As shown in Table 1, a vast majority (88.7%) of the  
9 surveyed BIM-based projects are still using the traditional DBB delivery method. The  
10 separated project delivery process, together with the lack of project incentive mechanisms,  
11 has critically impeded project participants to form an integrated team to collaboratively use  
12 BIM throughout the project lifecycle. As a result, nearly one third of the surveyed projects  
13 implement BIM only in a single project stage. Even for those projects that include  
14 multi-disciplinary BIM use, few project teams work collaboratively to share BIM models  
15 and, in many cases, the model development process is largely isolated from the daily design  
16 and construction processes. As a result, the models are often outdated and underutilised.

17 Other than quantifying current BIM practices in construction projects in China, this  
18 study also contributes to the knowledge of BIM through benchmarking BIM benefits.  
19 Based on case studies in different project contexts, previous studies have reported a variety  
20 of benefits arising from the use of BIM, such as fewer design errors, greater design  
21 productivity, more energy-efficient design solutions, fewer change orders, faster cost  
22 estimation and reduced production cycle times [4,8,9,35,38]. These studies collectively

1 indicate that using BIM can not only advance the effectiveness of project tasks but also  
2 improve the efficiency of design and construction activities. The results here generally  
3 support this and further indicate that, despite the considerable emphasis on visualization,  
4 the current use of BIM in the Chinese construction projects seems to have brought about  
5 more benefits in task effectiveness enhancement than in task efficiency improvement. The  
6 results also indicate that discrete BIM use in current practice could even reduce the  
7 productivity of early design activities. Since task efficiency improvement and task  
8 effectiveness enhancement generally benefit different types of project participants, and  
9 modeling efforts resulting in reduced productivity of early design activities could  
10 substantially improve the efficiency of later construction activities, these results could  
11 provide further evidence that BIM may potentially reshape the workloads and  
12 responsibilities of traditional project activities, and thus require the reallocation of risks and  
13 incentives among project participants.

14 Through statistically analysing the relationship between BIM practices and BIM  
15 effectiveness in different project contexts, this study further provides insights into how  
16 project attributes and BIM practice characteristics impact BIM benefits. Although  
17 conventional wisdom suggests that the decisions on BIM use need to be carefully  
18 considered according to the specific attributes of the target projects [5], little empirical  
19 evidence has been provided to assist in understanding the relationship between BIM use  
20 and project attributes. The present study partly corroborates this conventional argument  
21 through showing empirically that project attributes, especially project size, not only relate  
22 significantly to BIM use extent and client/owner support, but also significantly influence

1 the resultant project benefits of BIM use. After controlling for the effects of project  
2 attributes, however, this study further demonstrates that a more substantial contributing  
3 factor to BIM effectiveness lies in the extent of BIM use across different application areas.  
4 More comprehensive use results in not only greater improvements in task efficiency and  
5 effectiveness but also in greater success of the whole BIM use process, notwithstanding the  
6 continued persistence of data interoperability problems among different BIM applications.  
7 These results suggest that, while separately evaluating the appropriateness of using BIM in  
8 specific application areas according to related project characteristics, it is worthwhile  
9 employing a more comprehensive view of BIM and, whether through making better use of  
10 existing data exchange standards such as Industry Foundation Classes (IFC) or developing  
11 proprietary standards on the levels of data details in different application models, to better  
12 leverage the synergistic value of BIM in different application areas.

13 Clients/owners, who could potentially become both primary beneficiaries and  
14 important drivers of BIM use in construction projects, were also found to be an essential  
15 factor significantly influencing BIM success, especially in the aspects of task effectiveness  
16 improvement. While Becerik-Gerber and Rice's [68] investigation in the USA in 2009  
17 reported that most designers and contractors were still absorbing a large share of tangible  
18 BIM-related costs, the evidence in this study seems to be relatively favourable, with the  
19 majority of BIM costs in around half of the surveyed projects having been covered by the  
20 client/owner. Despite clients/owners increasingly assuming the responsibility for BIM costs,  
21 however, the study also indicates that clients/owners' overall support of BIM is still lacking  
22 to some extent. In residential building projects and smaller size projects, such support

1 appears to be even more limited. A noteworthy observation is that the perceived  
2 client/owner support in public projects is higher than that in private projects, but the related  
3 difference in the extent of BIM use is not found to be statistically significant. It seems that,  
4 in many public projects, client/owner support of BIM use is still primarily related to  
5 visualization needs, but neglects BIM potential in areas of model-based analysis and  
6 management. A number of public clients/owners around the world, such as the General  
7 Services Administration (GSA) in the United States and the Senate Properties in Finland,  
8 have already realized the core benefits of BIM and thus mandated BIM use in their projects.  
9 This is clearly an important area with great potential for public project clients/owners in  
10 China to learn and improve in the near future.

11

## 12 **6. Conclusions**

13 Despite its great potential, the advancement of BIM in the construction industry is still  
14 in a relatively infant stage. Published evaluations of current practices are required to  
15 provide momentum and insights for the future. Based on an investigation of 106 recent  
16 projects, this paper aims to provide an overview of current BIM practices in China, and  
17 assess how these practices differ from each other in their effectiveness. The results indicate  
18 that, through a decade of development, project BIM use in China has been clearly extended  
19 from the architectural design stage to the construction stage. Despite such a clear  
20 development, however, it is evident that in-depth BIM use is still limited principally to  
21 areas of visualization, with the aim of virtually representing complex facility shapes or  
22 conducting clash detections. In terms of participant involvement, general contractors and



1 designers are the two types of most frequent BIM users, and overall support of BIM by  
2 clients/owners is limited, despite their increasing absorption of BIM related costs. Although  
3 there are an increasing number of disciplines involved in BIM use, the problem of  
4 insufficient inter-organizational collaboration, which is partly caused by institutional  
5 regulations on the use of traditional project delivery systems, still seems to be particularly  
6 acute in current BIM practices in China. This paper further illustrates that current BIM  
7 practices, in terms of both the extent of BIM use and client/owner support, are significantly  
8 associated with project characteristics. The results also illustrate that the majority of BIM  
9 uses in the surveyed projects have positive outcomes in terms of improvements in both task  
10 efficiency and task effectiveness in the design and construction processes, although the  
11 benefits associated with the improvement of task effectiveness are more substantial than  
12 those related to efficiency improvement. Based on a series of hierarchical regression  
13 analyses, this paper further provides support for the argument that project characteristics  
14 are influential in the success of BIM use; however, they show that the influences of the  
15 extent of integrated use and client/owner support are more significant. In the Discussion  
16 section, the paper also compares BIM practices and effectiveness in China with those in  
17 other regions.

18 As reported in similar studies worldwide [28,35,66], it is apparent that the well-known  
19 potential for BIM has yet to be fully exploited in the Chinese construction industry. There  
20 is a potential for greater benefits to be obtained by a more systemic and comprehensive use  
21 of BIM in a wider variety of application areas over the project lifecycle. To take full  
22 advantage of this would involve a shift in current thinking of the use of BIM in discrete

1 applications to a more holistic approach involving reshaping the workloads and  
2 responsibilities of traditional project activities and the reallocation of risks and incentives  
3 among project participants. In doing this, and indeed as a precondition for such a transition,  
4 the current problems of interoperability among different BIM applications need to be  
5 further examined and addressed in terms of both technological interoperability and  
6 associated risk reallocation issues. To facilitate these changes, related institutional  
7 constraints on the use of more collaborative project delivery systems need to be addressed.  
8 Project clients/owners, especially those in public projects, should also be encouraged to  
9 play a more proactive role throughout the project lifecycle.

10 It should be noted that interpretation of the findings of this study is subject to several  
11 limitations. Firstly, the surveyed projects were not selected through a random sampling  
12 method. In order to improve the representativeness of the analysed projects, the samples  
13 were diversified with varied project sizes, natures, types and geographic locations.  
14 However, as better practices are more easily noticed by the industry and thus incorporated  
15 in this investigation, the extent of practical BIM use throughout the industry may be even  
16 lower than that shown within the surveyed projects. Secondly, with an intrinsic advantage  
17 of allowing replicability and thus enabling structured comparisons across different projects,  
18 a questionnaire survey was deployed as the main method to collect project-based data. This  
19 may generate potential problems of common method bias in the answers. However, this  
20 turns out to be less of a problem as Harman's one-factor test [69] showed that the single  
21 factor only accounts for 27.97% of the total variance in the measurements, indicating that  
22 common method bias is unlikely to be a substantial contaminant of the results. Thirdly,

1 while the use of BIM is still developing worldwide, this study can only provide a temporal  
2 snapshot of the evolving practices in the specific context in China. With the further  
3 evolution of BIM use around the world, it will be worthwhile to extend the examination  
4 framework, especially in application areas, to further compare evolving BIM practices in  
5 different regions and generalise the research findings on how BIM benefits are influenced  
6 by related project and practice characteristics.

7

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15

## 16 **References**

- 17 [1] H. Smyth, Construction industry performance improvement programmes: The UK case  
18 of demonstration projects in the 'continuous improvement' programme, Construction  
19 Management and Economics 28 (3) (2010) 255-270. DOI:  
20 <http://dx.doi.org/10.1080/01446190903505948>
- 21 [2] T.M. Froese, The impact of emerging information technology on project management  
22 for construction, Automation in Construction 19 (5) (2010) 531-538. DOI:

1 <http://dx.doi.org/10.1016/j.autcon.2009.11.004>

2 [3] H. Li, W. Lu, T. Huang, Rethinking project management and exploring virtual design  
3 and construction as a potential solution, *Construction Management and Economics* 27  
4 (4) (2009) 363-371. DOI: <http://dx.doi.org/10.1080/01446190902838217>

5 [4] C. Eastman, P. Teicholz, R. Sacks, K. Liston, *BIM Handbook: A Guide to Building*  
6 *Information Modeling for Owners, Managers, Designers, Engineers and Contractors*,  
7 2nd ed., John Wiley & Sons, Hoboken, NJ, 2011.

8 [5] Computer Integrated Construction Research Program (CICRP), *BIM Project Execution*  
9 *Planning Guide*, Dept. of Architecture Engineering, Pennsylvania State University,  
10 University Park, PA, 2011.

11 [6] H. Guo, H. Li, M. Skitmore, Life-cycle management of construction projects based on  
12 virtual prototyping technology, *Journal of Management in Engineering* 26 (1) (2010)  
13 41-47. DOI: [http://dx.doi.org/10.1061/\(ASCE\)0742-597X\(2010\)26:1\(41\)](http://dx.doi.org/10.1061/(ASCE)0742-597X(2010)26:1(41))

14 [7] T. Hartmann, J. Gao, M. Fischer, Areas of application for 3D and 4D models on  
15 construction projects, *Journal of Construction Engineering and Management* 134 (10)  
16 (2008) 776-785. DOI: [http://dx.doi.org/10.1016/\(ASCE\)0733-9364\(2008\)134:10\(776\)](http://dx.doi.org/10.1016/(ASCE)0733-9364(2008)134:10(776))

17 [8] D. Bryde, M. Broquetas, J.M. Volm, The project benefits of building information  
18 modelling (BIM), *International Journal of Project Management* 31 (7) (2013) 971-980.  
19 DOI: <http://dx.doi.org/10.1016/j.ijproman.2012.12.001>

20 [9] B.K. Giel, R.R.A. Issa, Return on investment analysis of using building information  
21 modeling in construction, *Journal of Computing in Civil Engineering* 27 (5) (2013)  
22 511-521. DOI: [http://dx.doi.org/10.1061/\(ASCE\)CP.1943-5487.0000164](http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000164)

- 1 [10] National Building Specification (NBS), National BIM Report 2013, NBS National  
2 BIM library, Newcastle upon Tyne, 2013.
- 3 [11] G. Lee, J. Lee, S.A. Jones, The Business Value of BIM in South Korea: How Building  
4 Information Modeling is Driving Positive Change in the South Korean Construction  
5 Industry, McGraw Hill Construction, Bedford, MA, 2012.
- 6 [12] R. Eadie, M. Browne, H. Odeyinka, C. McKeown, S. McNiff, BIM implementation  
7 throughout the UK construction project lifecycle: An analysis, Automation in  
8 Construction 36 (2013) 145-151. DOI: <http://dx.doi.org/10.1016/j.autcon.2013.09.001>
- 9 [13] S. Fox, J. Hietanen, Interorganizational use of building information models: Potential  
10 for automational, informational and transformational effects, Construction  
11 Management and Economics 25 (3) (2007) 289-296. DOI:  
12 <http://dx.doi.org/10.1080/01446190600892995>
- 13 [14] N. Gu, K. London, Understanding and facilitating BIM adoption in the AEC industry,  
14 Automation in Construction 19 (8) (2010) 988-999. DOI:  
15 <http://dx.doi.org/10.1016/j.autcon.2010.09.002>
- 16 [15] R. Howard, B. Björk, Building information modelling – experts’ views on  
17 standardisation and industry deployment, Advanced Engineering Informatics 22 (2)  
18 (2008) 271-280. DOI: <http://dx.doi.org/10.1016/j.aei.2007.03.001>
- 19 [16] A. Hanna, F. Boodai, M. El Asmar, State of practice of building information modeling  
20 in mechanical and electrical construction industries, Journal of Construction  
21 Engineering and Management 139 (10) (2013) 04013009. DOI:  
22 [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000747](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000747)

- 1 [17] C. Eastman, General purpose building description systems, Computer-Aided Design 8  
2 (1) (1976) 17-26. DOI: [http://dx.doi.org/10.1016/0010-4485\(76\)90005-1](http://dx.doi.org/10.1016/0010-4485(76)90005-1)
- 3 [18] B. Succar, Building information modelling framework: A research and delivery  
4 foundation for industry stakeholders, Automation in Construction 18 (3) (2009)  
5 357-375. DOI: <http://dx.doi.org/10.1016/j.autcon.2008.10.003>
- 6 [19] D. Castro-Lacouture, J.A. Sefair, L. Flórez, A.L. Medaglia, Optimization model for the  
7 selection of materials using a LEED-based green building rating system in Colombia,  
8 Building and Environment 44 (6) (2009) 1162-1170. DOI:  
9 <http://dx.doi.org/10.1016/j.buildenv.2008.08.009>
- 10 [20] J. Choi, J. Choi, I. Kim, Development of BIM-based evacuation regulation checking  
11 system for high-rise and complex buildings, Automation in Construction (2014), in  
12 press. DOI: <http://dx.doi.org/10.1016/j.autcon.2013.12.005>
- 13 [21] M. Golparvar-Fard, F. Peña-Mora, S. Savarese, Integrated sequential as-built and  
14 as-planned representation with tools in support of decision-making tasks in the  
15 AEC/FM industry, Journal of Construction Engineering and Management 137 (12)  
16 (2011) 1099-1116. DOI: [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000371](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000371)
- 17 [22] H.L. Guo, H. Li, V. Li, VP-based safety management in large-scale construction  
18 projects: A conceptual framework, Automation in Construction 34 (2013) 16-24. DOI:  
19 <http://dx.doi.org/10.1016/j.autcon.2012.10.013>
- 20 [23] X. Wang, P.E.D. Love, M.J. Kim, C. Park, C. Sing, L. Hou, A conceptual framework  
21 for integrating building information modeling with augmented reality, Automation in  
22 Construction 34 (2013) 37-44. DOI: <http://dx.doi.org/10.1016/j.autcon.2012.10.012>

- 1 [24] J.P. Zhang, Z.Z. Hu, BIM- and 4D-based integrated solution of analysis and  
2 management for conflicts and structural safety problems during construction: 1.  
3 principles and methodologies, *Automation in Construction* 20 (2) (2011) 155-166. DOI:  
4 <http://dx.doi.org/10.1016/j.autcon.2010.09.013>
- 5 [25] D. Di Mascio, X. Wang, Building information modelling (BIM)-supported cooperative  
6 design in sustainable renovation projects, *Lecture Notes in Computer Science* 8091  
7 (2013) 205-212. DOI: [http://dx.doi.org/10.1007/978-3-642-40840-3\\_30](http://dx.doi.org/10.1007/978-3-642-40840-3_30)
- 8 [26] Y. Wang, X. Wang, J. Wang, P. Yung, J. Guo, Engagement of facilities management in  
9 design stage through BIM: Framework and a case study, *Advances in Civil*  
10 *Engineering* (2013) 189105. DOI: <http://dx.doi.org/10.1155/2013/189105>
- 11 [27] T. Cerovsek, A review and outlook for a 'Building information model' (BIM): A  
12 multi-standpoint framework for technological development, *Advanced Engineering*  
13 *Informatics* 25 (2) (2011) 224-244. DOI: <http://dx.doi.org/10.1016/j.aei.2010.06.003>
- 14 [28] C. Eastman, Y. Jeong, R. Sacks, I. Kaner, Exchange model and exchange object  
15 concepts for implementation of national BIM standards, *Journal of Computing in Civil*  
16 *Engineering* 24 (1) (2010) 25-34. DOI:  
17 [http://dx.doi.org/10.1061/\(ASCE\)0887-3801\(2010\)24:1\(25\)](http://dx.doi.org/10.1061/(ASCE)0887-3801(2010)24:1(25))
- 18 [29] A. Redmond, A. Hore, M. Alshawi, R. West, Exploring how information exchanges  
19 can be enhanced through cloud BIM, *Automation in Construction* 24 (2012) 175-183.  
20 DOI: <http://dx.doi.org/10.1016/j.autcon.2012.02.003>
- 21 [30] V. Singh, N. Gu, X. Wang, A theoretical framework of a BIM-based multi-disciplinary  
22 collaboration platform, *Automation in Construction* 20 (2) (2011) 134-144. DOI:

- 1 <http://dx.doi.org/10.1016/j.autcon.2010.09.011>
- 2 [31] R. Davies, C. Harty, Implementing 'Site BIM': A case study of ICT innovation on a  
3 large hospital project, *Automation in Construction* 30 (2013) 15-24. DOI:  
4 <http://dx.doi.org/10.1016/j.autcon.2012.11.024>
- 5 [32] A. Khanzode, M. Fischer, D. Reed, Benefits and lessons learned of implementing  
6 building virtual design and construction (VDC) technologies for coordination of  
7 mechanical, electrical, and plumbing (MEP) systems on a large healthcare project,  
8 *Journal of Information Technology in Construction* 13 (2008) 324-342.
- 9 [33] R. Manning, J. Messner, Case studies in BIM implementation for programming of  
10 healthcare facilities, *Journal of Information Technology in Construction* 13 (2008)  
11 246-257.
- 12 [34] R.K. Yin, *Case Study Research: Design and Methods*, 4th ed., Sage Publications,  
13 Thousand Oaks, CA, 2009.
- 14 [35] J. Gao, M. Fischer, *Framework and Case Studies Comparing Implementations and*  
15 *Impacts of 3D/4D Modeling Across Projects*, Center for Integrated Facility  
16 Engineering, Stanford University, Stanford, CA, 2008.
- 17 [36] J. Taylor, P. Bernstein, Paradigm trajectories of building information modeling practice  
18 in project networks, *Journal of Management in Engineering* 25 (2) (2009) 69-76. DOI:  
19 [http://dx.doi.org/10.1061/\(ASCE\)0742-597X\(2009\)25:2\(69\)](http://dx.doi.org/10.1061/(ASCE)0742-597X(2009)25:2(69))
- 20 [37] K. Barlish, K. Sullivan, How to measure the benefits of BIM - A case study approach,  
21 *Automation in Construction* 24 (2012) 149-159. DOI:  
22 <http://dx.doi.org/10.1016/j.autcon.2012.02.008>



- 1 [38] S. Azhar, Building information modeling (BIM): Trends, benefits, risks, and  
2 challenges for the AEC industry, *Leadership and Management in Engineering* 11 (3)  
3 (2011) 241-252. [http://dx.doi.org/10.1061/\(ASCE\)LM.1943-5630.0000127](http://dx.doi.org/10.1061/(ASCE)LM.1943-5630.0000127)
- 4 [39] K.M. Eisenhardt, Building theories from case study research, *The Academy of*  
5 *Management Review* 14 (4) (1989) 532-550. DOI:  
6 <http://dx.doi.org/10.5465/AMR.1989.4308385>
- 7 [40] M.J. Salganik, D.D. Heckathorn, Sampling and estimation in hidden populations using  
8 respondent-driven sampling, *Sociological Methodology* 34 (1) (2004) 193-240. DOI:  
9 <http://dx.doi.org/10.1111/j.0081-1750.2004.00152.x>
- 10 [41] K.K. Boyer, R. Verma, Multiple raters in survey-based operations management  
11 research: A review and tutorial, *Production and Operations Management* 9 (2) (2000)  
12 128-140. DOI: <http://dx.doi.org/10.1111/j.1937-5956.2000.tb00329.x>
- 13 [42] D. Cao, H. Li, G. Wang, Impacts of isomorphic pressures on BIM adoption in  
14 construction projects, *Journal of Construction Engineering and Management* (2014), in  
15 press. DOI: [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000903](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000903)
- 16 [43] S. Azhar, W.A. Carlton, D. Olsen, I. Ahmad, Building information modeling for  
17 sustainable design and LEED<sup>®</sup> rating analysis, *Automation in Construction* 20 (2)  
18 (2011) 217-224. DOI: <http://dx.doi.org/10.1016/j.autcon.2010.09.019>
- 19 [44] U. Isikdag, J. Underwood, G. Aouad, An investigation into the applicability of building  
20 information models in geospatial environment in support of site selection and fire  
21 response management processes, *Advanced Engineering Informatics* 22 (4) (2008)  
22 504-519. DOI: <http://dx.doi.org/10.1016/j.aei.2008.06.001>

- 1 [45] J. Schade, T. Olofsson, M. Schreyer, Decision- making in a model- based design  
2 process, *Construction Management and Economics* 29 (4) (2011). DOI:  
3 <http://dx.doi.org/10.1080/01446193.2011.552510>
- 4 [46] F.K.T. Cheung, J. Rihan, J. Tah, D. Duce, E. Kurul, Early stage multi-level cost  
5 estimation for schematic BIM models, *Automation in Construction* 27 (2012) 67-77.  
6 DOI: <http://dx.doi.org/10.1016/j.autcon.2012.05.008>
- 7 [47] P. Bynum, R. Issa, S. Olbina, Building information modeling in support of sustainable  
8 design and construction, *Journal of Construction Engineering and Management* 139 (1)  
9 (2013) 24-34. DOI: [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000560](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000560)
- 10 [48] A. Schlueter, F. Thesseling, Building information model based energy/exergy  
11 performance assessment in early design stages, *Automation in Construction* 18 (2)  
12 (2009) 153-163. DOI: <http://dx.doi.org/10.1016/j.autcon.2008.07.003>
- 13 [49] U. Rueppel, K.M. Stuebbe, BIM-based indoor-emergency-navigation-system for  
14 complex buildings, *Tsinghua Science & Technology* 13 (S1) (2008) 362-367. DOI:  
15 [http://dx.doi.org/10.1016/S1007-0214\(08\)70175-5](http://dx.doi.org/10.1016/S1007-0214(08)70175-5)
- 16 [50] H. Li, N.K.Y. Chan, T. Huang, M. Skitmore, J. Yang, Virtual prototyping for planning  
17 bridge construction, *Automation in Construction* 27 (2012) 1-10. DOI:  
18 <http://dx.doi.org/10.1016/j.autcon.2012.04.009>
- 19 [51] A. Monteiro, J. Poças Martins, A survey on modeling guidelines for quantity  
20 takeoff-oriented BIM-based design, *Automation in Construction* 35 (2013) 238-253.  
21 DOI: <http://dx.doi.org/10.1016/j.autcon.2013.05.005>
- 22 [52] S. Chin, S. Yoon, C. Choi, C. Cho, RFID + 4D for progress management of structural

- 1 steel works in high-rise buildings, *Journal of Computing in Civil Engineering* 22 (2)  
2 (2008) 74-89. DOI: [http://dx.doi.org/10.1061/\(ASCE\)0887-3801\(2008\)22:2\(74\)](http://dx.doi.org/10.1061/(ASCE)0887-3801(2008)22:2(74))
- 3 [53] K.E. Larsen, F. Lattke, S. Ott, S. Winter, Surveying and digital workflow in energy  
4 performance retrofit projects using prefabricated elements, *Automation in Construction*  
5 20 (8) (2011) 999-1011. DOI: <http://dx.doi.org/10.1016/j.autcon.2011.04.001>
- 6 [54] H. Li, H.L. Guo, M. Skitmore, T. Huang, K.Y.N. Chan, G. Chan, Rethinking  
7 prefabricated construction management using the VP-based IKEA model in Hong  
8 Kong, *Construction Management and Economics* 29 (3) (2011) 233-245. DOI:  
9 <http://dx.doi.org/10.1080/01446193.2010.545994>
- 10 [55] F. Ling, A. Hartmann, M. Kumaraswamy, M. Dulaimi, Influences on innovation  
11 benefits during implementation: Client's perspective, *Journal of Construction*  
12 *Engineering and Management* 133 (4) (2007) 306-315. DOI:  
13 [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2007\)133:4\(306\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2007)133:4(306))
- 14 [56] G. Winch, *Managing Construction Projects: An Information Processing Approach*, 2nd  
15 ed., Wiley-Blackwell, Oxford, 2010.
- 16 [57] Y. Zhu, Y. Li, W. Wang, J. Chen, What leads to post-implementation success of ERP?  
17 an empirical study of the Chinese retail industry, *International Journal of Information*  
18 *Management* 30 (3) (2010) 265-276. DOI:  
19 <http://dx.doi.org/10.1016/j.ijinfomgt.2009.09.007>
- 20 [58] T.F. Gattiker, D.L. Goodhue, What happens after ERP implementation: Understanding  
21 the impact of interdependence and differentiation on plant-level outcomes, *MIS*  
22 *Quarterly* 29 (3) (2005) 559-585. URL: <http://www.jstor.org/stable/25148695>

- 1 [59] S. Hung, S. Chang, D.C. Yen, T. Kang, C. Kuo, Successful implementation of  
2 collaborative product commerce: An organizational fit perspective, *Decision Support*  
3 *Systems* 50 (2) (2011) 501-510. DOI: <http://dx.doi.org/10.1016/j.dss.2010.11.007>
- 4 [60] M. Hoegl, H.G. Gemuenden, Teamwork quality and the success of innovative projects:  
5 A theoretical concept and empirical evidence, *Organization Science* 12 (4) (2001)  
6 435-449. DOI: <http://dx.doi.org/10.1287/orsc.12.4.435.10635>
- 7 [61] J.C. Nunnally, *Psychometric Theory*, 2d ed., McGraw-Hill, New York, 1978.
- 8 [62] H.M. Bernstein, S.A. Jones, J.E. Gudgel, et al., *The Business Value of BIM in Europe:*  
9 *Getting Building Information Modeling to the Bottom Line in the United Kingdom,*  
10 *France and Germany*, McGraw Hill Construction, Bedford, MA, 2010.
- 11 [63] B. Becerik-Gerber, F. Jazizadeh, N. Li, G. Calis, Application areas and data  
12 requirements for BIM-enabled facilities management, *Journal of Construction*  
13 *Engineering and Management* 138 (3) (2012) 431-442. DOI:  
14 [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000433](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000433)
- 15 [64] H.M. Bernstein, S.A. Jones, M.A. Russo, et al., *The Business Value of BIM in North*  
16 *America*, McGraw Hill Construction, Bedford, MA, 2012.
- 17 [65] A. Gerrard, J. Zuo, G. Zillante, M. Skitmore, Building information modelling in the  
18 Australian architecture, engineering and construction industry, in: J. Underwood, U.  
19 Isikdag (Eds.), *Handbook of Research on Building Information Modeling and*  
20 *Construction Informatics: Concepts and Technologies*, Information Science Reference,  
21 Information Science Publishing, Hershey, PA, 2010, pp. 521-544. DOI:  
22 <http://dx.doi.org/10.4018/978-1-60566-928-1.ch023>

- 1 [66] T. McCuen, P. Suermann, M. Krogulecki, Evaluating award-winning BIM projects  
2 using the National Building Information Model Standard Capability Maturity Model,  
3 Journal of Management in Engineering 28 (2) (2012) 224-230. DOI:  
4 [http://dx.doi.org/10.1061/\(ASCE\)ME.1943-5479.0000062](http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000062)
- 5 [67] C. Dossick, G. Neff, Organizational divisions in BIM-enabled commercial  
6 construction, Journal of Construction Engineering and Management 136 (4) (2010)  
7 459-467. DOI: [http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000109](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000109)
- 8 [68] B. Becerik-Gerber, S. Rice, The perceived value of building information modeling in  
9 the U.S. building industry, Journal of Information Technology in Construction 15  
10 (2010) 185-201.
- 11 [69] P.M. Podsakoff, D.W. Organ, Self-reports in organizational research: Problems and  
12 prospects, Journal of Management 12 (4) (1986) 531-544. DOI:  
13 <http://dx.doi.org/10.1177/014920638601200408>

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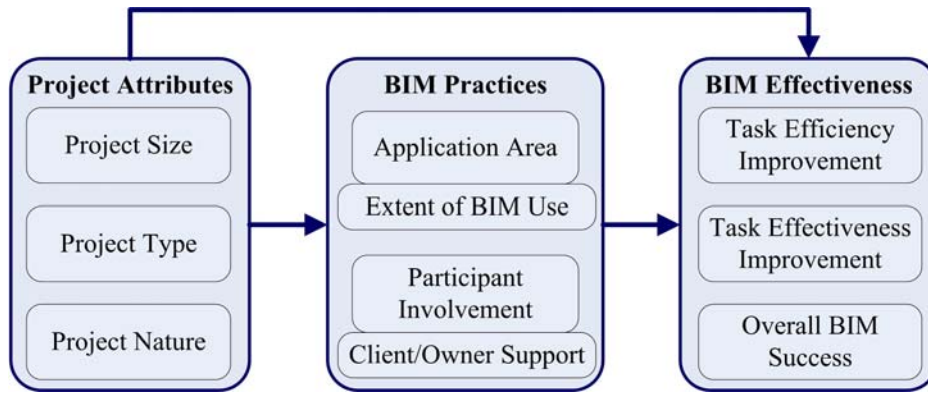
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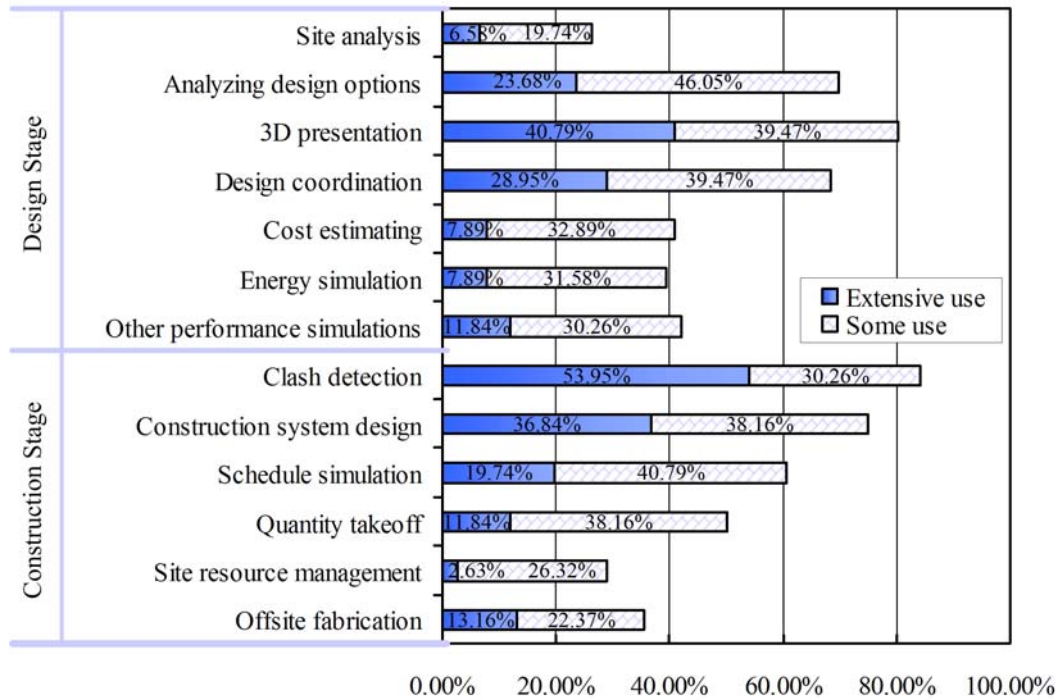
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**Figure 1** Conceptual research model



**Figure 2** BIM practices in different application areas



**Table 1**

Project demographic information.

Variable	Category	Number	Percentage	Variable	Category	Number	Percentage	
Year <sup>a</sup>	2007	1	0.9	Project size	Below ¥50 million	12	11.3	
	2008	8	7.5		¥50-200 million	24	22.6	
	2009	11	10.4		¥200-1000 million	32	30.2	
	2010	14	13.2		Above ¥1000 million	38	35.8	
	2011	20	18.9		Project type	Residential	14	13.2
	2012	35	33.0			Commercial	38	35.8
	2013	17	16.0			Cultural	19	17.9
Location	North China	17	16.0	Sporting		4	3.8	
	Northeast China	4	3.8	Hospital	4	3.8		
	East China	51	48.1	Transportation	11	10.4		
	South Central China	22	20.8	Industrial	14	13.2		
	Southwest China	6	5.7	Others	2	1.9		
	Northwest China	6	5.7	Project delivery system	DBB <sup>b</sup>	94	88.7	
Project nature	Public	50	47.2		EPC/DB <sup>c</sup>	10	9.4	
	Private	56	52.8	Others	2	1.9		

<sup>a</sup> Year for the commencement of construction activities.<sup>b</sup> Design-Bid-Build.<sup>c</sup> EPC = Engineering, procurement and construction, DB = Design-Build.

**Table 2**

BIM application areas in design and construction stages [42].

Stage	Application area	Description	References
Design Stage	Site analysis	Analyzing project site location	[5,43,44]
	Analyzing design options	Exploring and comparing design options based on 3D models	[4,5,7,35,45]
	3D presentation	Three-dimensional (3D) presentation of complex structures to non-professionals	[4,7,35]
	Design coordination	Coordinating design of architectural, structural, and MEP systems	[4,5,7,35]
	Cost estimating	Project cost estimating during design stage	[4,5,7,35,46]
	Energy simulation	Analyzing building's energy distribution and consumption	[4,5,43,47,48]
	Other performance simulations	Analyzing building's other performances such as lighting, acoustics, ventilation and air flows, and pedestrian circulation	[4,5,43,47,49]
Construction Stage	Clash detection	Checking conflicts among building systems prior to construction	[4,5,7,35]
	Construction system design	Designing and analyzing the construction of complex building systems in order to increase planning	[4,5,7,35,50]
	Schedule simulation	Simulating master schedules and construction sequences	[4,5,7,35]
	Quantity takeoff	Quantity takeoff and cost estimation during construction stage	[4,5,7,35,51]
	Site resource management	Integration with schedules and onsite information to manage the storage and procurement processes of project materials and equipments	[4,7,35,52]
	Offsite fabrication	Generating digitized information to facilitate greater use of prefabricated components	[4,5,35,53,54]

**Table 3**

Measurement items of client/owner support and effectiveness constructs.

Construct	Items	References
Client/owner support (COS)	Client/owner has invested substantial resources in BIM use in the project Client/owner regards BIM use as a priority of project activities Client/owner has put much effort in driving project participants to collaboratively use BIM	[42,57]
Task efficiency improvement (TEY)	BIM facilitates the automatic and fast execution of design and construction activities BIM increases productivity in related design and construction processes BIM saves time for project participants to conduct related design and construction activities	[35,58]
Task effectiveness improvement (TES)	BIM reduces errors and rework in design and construction activities BIM has helped this project to explore better design/construction solutions with higher quality, less cost and fewer energy consumption BIM enables related design and construction activities to add more value to project client/owner	[35,60]
Overall BIM success (OBS)	In terms of its overall impact on this project, the BIM use has been a success BIM has seriously improved this project's overall performance on quality, cost, schedule and sustainability From the perspective of this project, the costs of BIM use outweigh the benefits The overall performance of BIM use in this project has satisfactorily achieved the expected level	[58,59]

**Table 4**

Validity measures and construct correlations.

Construct	CR <sup>a</sup>	AVE <sup>b</sup>	Correlation matrix <sup>c</sup>			
			COS	TEY	TES	OIS
Client/owner support (COS)	0.970	0.914	<b>0.956</b>			
Task efficiency improvement (TEY)	0.936	0.830	0.331	<b>0.911</b>		
Task effectiveness improvement (TES)	0.924	0.802	0.416	0.326	<b>0.895</b>	
Overall BIM success (OBS)	0.929	0.766	0.489	0.535	0.506	<b>0.875</b>

<sup>a</sup> Composite reliability.<sup>b</sup> Average variance extracted.<sup>c</sup> Bold values on the diagonal represent the square root of AVE.

**Table 5**

Influences of project attributes on extent of BIM use: Linear regression results.

Independent variable	Coefficient <sup>a</sup>	R <sup>2</sup>	F-value	p-value
Project size	0.211*	0.045	4.852	0.030
Project type <sup>b</sup>	0.203*	0.041	4.465	0.037
Project nature <sup>c</sup>	-0.054	0.003	0.306	0.582

<sup>a</sup> Standardized regression coefficients ( $\beta$ ) are reported.

<sup>b</sup> Projects are dichotomously classified as residential and non-residential types: "1" represents residential project, "2" represents non-residential project.

<sup>c</sup> "1" represents public project, "2" represents private project.

\*  $P < 0.05$ .

**Table 6**

Roles of project participants in BIM use.

Participant	Roles		
	Leading	Participating	Not involved
Client/owner	21 (19.81%)	55 (51.89%)	30 (28.30%)
Designer	43 (40.57%)	38 (35.85%)	25 (23.58%)
General contractor	30 (28.30%)	58 (54.72%)	18 (16.98%)
Subcontractors	3 (2.83%)	49 (46.23%)	54 (50.94%)
BIM consultant	9 (8.49%)	25 (23.58%)	72 (67.92%)

Note: Values outside parentheses are project frequencies and values inside represent percentages (totals may not add to 100.00% due to rounding).

**Table 7**

ANOVA test for client/owner support of BIM use by project attributes.

Project attributes		N <sup>a</sup>	Mean	SD		SS <sup>b</sup>	F-value	p-value
Size	Below ¥50 million	11	3.12	0.95	Between groups	22.89	4.27	0.007
	¥50-200 million	21	4.17	1.29	Within groups	157.27		
	¥200-1000 million	30	3.88	1.48	Total	180.16		
	Above ¥1000 million	30	4.70	1.34				
	Total	92	4.12	1.41				
Type	Residential	11	3.30	1.38	Between groups	8.40	4.40	0.039
	Non-residential	81	4.23	1.38	Within groups	171.76		
	Total	92	4.12	1.41	Total	180.16		
Nature	Public project	43	4.46	1.42	Between groups	9.02	4.74	0.032
	Private project	49	3.83	1.34	Within groups	171.14		
	Total	92	4.12	1.41	Total	180.16		

<sup>a</sup> To mitigate response bias, 14 responses from project clients/owners were excluded.<sup>b</sup> SS = sum of squares.

**Table 8**

ANOVA test for BIM effectiveness by project stages.

Variables	Stage	N	Mean	SD		SS	F-value	p-value
Task efficiency improvement	Within design stage	12	3.83	1.21	Between groups	15.73	5.81	0.004
	Within construction stage	21	4.87	1.03	Within groups	139.54		
	Within D&C stages <sup>a</sup>	73	5.07	1.19	Total	155.27		
	Total	106	4.89	1.22				
Task effectiveness improvement	Within design stage	12	5.00	1.01	Between groups	4.25	2.67	0.074
	Within construction stage	21	5.03	0.72	Within groups	81.84		
	Within D&C stages	73	5.45	0.92	Total	86.08		
	Total	106	5.32	0.91				
Overall BIM success	Within design stage	12	4.48	0.55	Between groups	4.13	2.48	0.088
	Within construction stage	21	4.93	0.41	Within groups	85.68		
	Within D&C stages	73	5.10	1.05	Total	89.81		
	Total	106	5.00	0.92				

<sup>a</sup> D&C = design and construction.



**Table 9**

Influences of project and practice characteristics on BIM effectiveness: Hierarchical regression results.

Variables	TEY <sup>a</sup>			TES <sup>a</sup>			OBS <sup>a</sup>		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
Project size	0.262*	2.224*	0.205*	0.107	0.057	0.001	0.224*	0.152	0.111
Project type <sup>b</sup>	0.149	0.846	0.081	0.134	0.064	0.051	-0.021	-0.121	-0.131
Project nature	-0.173	-1.795	-0.162	-0.031	-0.027	0.021	-0.136	-0.131	-0.096
Extent of BIM use		3.392**	0.304**		0.347**	0.225*		0.497**	0.408**
Client/owner support			0.054			0.306**			0.223*
R <sup>2</sup>	0.165	0.263	0.265	0.040	0.151	0.219	0.075	0.303	0.339
F-value	5.803	7.749	6.193	1.236	3.874	4.813	2.381	9.445	8.808
p-value	0.001	0.000	0.000	0.301	0.006	0.001	0.075	0.000	0.000
Change in R <sup>2</sup>		0.098	0.002		0.111	0.067		0.228	0.036
Change in F-value		11.507	0.242		11.351	7.426		28.409	4.670
p-value (change)		0.001	0.624		0.001	0.008		0.000	0.033

<sup>a</sup> Standardized regression coefficients ( $\beta$ ) are reported; N = 92, as 14 client/owner responses were excluded.<sup>b</sup> Projects are dichotomously classified as residential and non-residential types: "1" represents residential project, "2" represents non-residential project.

\* P &lt; 0.05; \*\* P &lt; 0.01.