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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. Introduction

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

Despite its great potential, the advancement of BIM in the construction industry is still in a relatively infant stage, and the technology's actual diffusion rate among industry practitioners worldwide is still much lower than expected [10]. For those practitioners who have already been involved in BIM use, a relatively high percentage is still "just scratching the surface of how much value BIM can provide" [11]. While there are currently a variety of issues impeding the progress of BIM in the industry [12-15], one of the most effective facilitating manoeuvres lies in eliciting experiences and lessons from current BIM practices to provide momentum and insights for the future [7,8,16].

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

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

2. Research background

The concept of BIM can be traced back to the working prototype "building description systems" proposed by Eastman in the mid 1970s [17]. Due to its great potential benefits but still relatively limited application in practice, BIM has become a highly active research topic in recent years [3,18]. The vast majority of studies have focused primarily on technical issues, including exploring potential areas in which BIM could be beneficially used [19-26] and enhancing interoperability among different modeling tools [27-30]. The purposes of these studies mainly relate to validating or improving the technical feasibility of related BIM prototypes, including the further integration of these prototypes with other technologies such as laser scanning and radio frequency identification (RFID).

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

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

< Insert Fig. 1 here >

3. Research method

3.1. Survey instrument

This study is part of an industry-wide investigation to assess the state of BIM adoption and implementation practices in the Chinese construction industry. With its intrinsic advantage of allowing replicability and thus enabling structured comparisons across different projects, a questionnaire survey was used as the main method of collecting project-based data. Following Eisenhardt [39], a mix of other data collection methods, including interviews, direct observation and document analysis, was also used in order to better design the survey and to gain more detailed information relating to the surveyed projects.

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

The questionnaire associated with this study was structured into four sections. The first section concentrates on general information of the surveyed project. The second section evaluates the extent to which BIM has been used in different application areas. The third section focuses on the roles of the key project participants involved. In the last section, respondents are asked for their perceptions of the effectiveness of BIM usage in the surveyed projects.

3.2. Sampling and data collection

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

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

< Insert Table 1 here >

Among the 106 project-specific responses, 47.2% were collected through e-mail, with the remaining 37.7% and 15.1% collected by personal visits and the online survey system respectively. An analysis of variance (ANOVA) was conducted to compare the answers from the three types of responses, and no statistically significant differences were identified. The respondents were from a mix of project participants, with 13.2% from clients/owners, 34.9% from designers, 32.1% from general contractors (including EPC/DB contractors), 15.0% from consultants and 4.7% from subcontractors. Most respondents were senior and professional individuals knowledgeable of BIM use, with 29.2% being project managers or chief project engineers, 17.9% BIM managers, 24.5% BIM engineers, and the remaining 28.3% being other types of engineers also directly involved in the use of BIM.

3.3. Measurements and construct validity

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

< Insert Table 2 here >

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

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

< Insert Table 3 here >

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

< Insert Table 4 here >

4. Analyses and results

4.1. Application areas

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

< Insert Fig. 2 here >

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

In order to examine the relationship between project attributes and BIM use practices, a principal component analysis (PCA) was performed to aggregate the BIM usage in the 13 application areas into one summated factor, and the factor scores then used as dependent variable values to perform three separate linear regressions on the influences of project size, project type and project nature. A test for internal consistency of the summated factor, which is used to measure the extent of BIM use as a whole in each project, yields a satisfactory Cronbach’s Alpha of 0.805. As shown in Table 5, project size and project type are both significant predictors of the extent of project BIM use. The influence of project nature on the other hand is not found to be significant. Follow-up contact and further examination of the survey data indicate that, even though government-investment projects generally possess more resources to invest in innovative technologies, in many public projects BIM is still deployed primarily as a visualization tool, especially in stadium and exhibition hall projects due to their specific needs to represent complex designs to the public and non-professional clients/owners.

< Insert Table 5 here >

4.2. Participant involvement and client/owner support

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

< Insert Table 6 here >

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

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

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

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

< Insert Table 7 here >

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

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

4.3. BIM effectiveness and its association with BIM usage characteristics

The respondents' perceived effectiveness of BIM is partly presented in Table 8, with the relatively positive results in task efficiency improvement (mean = 4.89, SD = 1.22), task effectiveness improvement (mean = 5.32, SD = 0.91) and overall BIM success (mean = 5.00, SD = 0.92). Specifically, only 17.92% of the surveyed projects have OBS mean scores not exceeding the threshold value of 4, indicating the use of BIM to have positive outcomes in the majority of the projects. A paired-samples t-test indicates the mean score of TES to be statistically higher than that of TEY ($t = 3.50$, $p < 0.001$), suggesting that BIM has brought about more benefits in advancing project task quality than in improving design and construction productivity.

< Insert Table 8 here >

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

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

In order to further understand how higher levels of integration contribute to improving BIM effectiveness, hierarchical regression analysis was used to test the relationships between BIM practice characteristics and effectiveness variables. This enables the incremental effects of BIM use extent and client/owner support to be examined by controlling for the effects of project attributes. A total of three separate hierarchical regressions were performed, which employed TEY, TES and OBS as their dependent variables respectively. For each of these regressions, the blocks of independent variables were entered individually, starting with control variables (model 1), then the extent of BIM use (model 2), and finally client/owner support (model 3). The results of these regressions are presented in Table 9.

< Insert Table 9 here >

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

5. Discussions and implications

While government agencies in several countries (e.g., Singapore, South Korea, the UK, and the USA) have already established plans for the mandatory use of BIM for public projects, the Chinese government has not yet issued any nationwide regulations to mandate BIM deployment and, therefore, the evolution of BIM practices in China has primarily been regulated by the marketplace during the past decade. Compared with early practices (specifically in those projects built for the 2008 Beijing Olympic Games around 2004) in which BIM was predominantly used to visualize complex facility shapes during the architectural design stage, a distinct characteristic of BIM practices in the surveyed projects of the present study is that BIM use has been frequently extended to application areas within the construction stage. Such a change seems to be relatively inspiring as some recent investigations, such as Eadie et al.'s survey in the UK in 2012 [12] and the SmartMarket survey in Western Europe in 2010 [62], show that in some developed countries contractors are still significantly less frequently involved in BIM use than designers, and many BIM practices are still limited to the design stage. Such a change also seems to be similar with what has happened in North America, where BIM has been increasingly used during the construction stage [63] and the BIM adoption rate among contractors is reported to have surpassed that of designers [64]. There are several reasons for this change. As it is required to submit 2D project documentation for regulatory approvals but it is still difficult for BIM software applications to automatically generate 2D shop drawings in accordance with industry specifications in China, BIM use is often regarded as extra work by the designers with fixed fee contracts. As for contractors within the highly fierce competition environment of the construction market, however, they often have internal incentives to actively embrace innovative technologies such as BIM to effectively manage construction activities or to win more construction contracts. As a result, several large-sized contractors, such as the China State Construction Engineering Corporation, have already established corporation-wide mechanisms of staff training and project awards to facilitate the diffusion of BIM in their subsidiaries.

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

While collaboration problems related to integrated BIM use have been reported in many countries [11,14,67], such problems caused by the use of traditional project delivery systems seem to be particularly severe in China at present. According to Becerik-Gerber and Rice's survey in the US construction industry in 2009 [68], the majority of BIM-based construction projects were being delivered through relatively collaborative methods such as integrated project delivery (IPD) and design-build (DB) to better leverage BIM benefits, and only 32.7% were being delivered through the traditional design-bid-build (DBB) system. Limited by a number of regulations on the project execution processes and related bidding mechanisms in the Chinese construction industry, however, design and construction services in most Chinese mainland construction projects are procured separately through the traditional DBB method. Such a situation has not changed markedly with the advent of BIM in the industry. As shown in Table 1, a vast majority (88.7%) of the surveyed BIM-based projects are still using the traditional DBB delivery method. The separated project delivery process, together with the lack of project incentive mechanisms, has critically impeded project participants to form an integrated team to collaboratively use BIM throughout the project lifecycle. As a result, nearly one third of the surveyed projects implement BIM only in a single project stage. Even for those projects that include multi-disciplinary BIM use, few project teams work collaboratively to share BIM models and, in many cases, the model development process is largely isolated from the daily design and construction processes. As a result, the models are often outdated and underutilised.

Other than quantifying current BIM practices in construction projects in China, this study also contributes to the knowledge of BIM through benchmarking BIM benefits. Based on case studies in different project contexts, previous studies have reported a variety of benefits arising from the use of BIM, such as fewer design errors, greater design productivity, more energy-efficient design solutions, fewer change orders, faster cost estimation and reduced production cycle times [4,8,9,35,38]. These studies collectively indicate that using BIM can not only advance the effectiveness of project tasks but also improve the efficiency of design and construction activities. The results here generally support this and further indicate that, despite the considerable emphasis on visualization, the current use of BIM in the Chinese construction projects seems to have brought about more benefits in task effectiveness enhancement than in task efficiency improvement. The results also indicate that discrete BIM use in current practice could even reduce the productivity of early design activities. Since task efficiency improvement and task effectiveness enhancement generally benefit different types of project participants, and modeling efforts resulting in reduced productivity of early design activities could substantially improve the efficiency of later construction activities, these results could provide further evidence that BIM may potentially reshape the workloads and responsibilities of traditional project activities, and thus require the reallocation of risks and incentives among project participants.

Through statistically analysing the relationship between BIM practices and BIM effectiveness in different project contexts, this study further provides insights into how project attributes and BIM practice characteristics impact BIM benefits. Although conventional wisdom suggests that the decisions on BIM use need to be carefully considered according to the specific attributes of the target projects [5], little empirical evidence has been provided to assist in understanding the relationship between BIM use and project attributes. The present study partly corroborates this conventional argument through showing empirically that project attributes, especially project size, not only relate significantly to BIM use extent and client/owner support, but also significantly influence the resultant project benefits of BIM use. After controlling for the effects of project attributes, however, this study further demonstrates that a more substantial contributing factor to BIM effectiveness lies in the extent of BIM use across different application areas. More comprehensive use results in not only greater improvements in task efficiency and effectiveness but also in greater success of the whole BIM use process, notwithstanding the continued persistence of data interoperability problems among different BIM applications. These results suggest that, while separately evaluating the appropriateness of using BIM in specific application areas according to related project characteristics, it is worthwhile employing a more comprehensive view of BIM and, whether through making better use of existing data exchange standards such as Industry Foundation Classes (IFC) or developing proprietary standards on the levels of data details in different application models, to better leverage the synergistic value of BIM in different application areas.

Clients/owners, who could potentially become both primary beneficiaries and important drivers of BIM use in construction projects, were also found to be an essential factor significantly influencing BIM success, especially in the aspects of task effectiveness improvement. While Becerik-Gerber and Rice's [68] investigation in the USA in 2009 reported that most designers and contractors were still absorbing a large share of tangible BIM-related costs, the evidence in this study seems to be relatively favourable, with the majority of BIM costs in around half of the surveyed projects having been covered by the client/owner. Despite clients/owners increasingly assuming the responsibility for BIM costs, however, the study also indicates that clients/owners' overall support of BIM is still lacking to some extent. In residential building projects and smaller size projects, such support appears to be even more limited. A noteworthy observation is that the perceived client/owner support in public projects is higher than that in private projects, but the related difference in the extent of BIM use is not found to be statistically significant. It seems that, in many public projects, client/owner support of BIM use is still primarily related to visualization needs, but neglects BIM potential in areas of model-based analysis and management. A number of public clients/owners around the world, such as the General Services Administration (GSA) in the United States and the Senate Properties in Finland, have already realized the core benefits of BIM and thus mandated BIM use in their projects. This is clearly an important area with great potential for public project clients/owners in China to learn and improve in the near future.

6. Conclusions

Despite its great potential, the advancement of BIM in the construction industry is still in a relatively infant stage. Published evaluations of current practices are required to provide momentum and insights for the future. Based on an investigation of 106 recent projects, this paper aims to provide an overview of current BIM practices in China, and assess how these practices differ from each other in their effectiveness. The results indicate that, through a decade of development, project BIM use in China has been clearly extended from the architectural design stage to the construction stage. Despite such a clear development, however, it is evident that in-depth BIM use is still limited principally to areas of visualization, with the aim of virtually representing complex facility shapes or conducting clash detections. In terms of participant involvement, general contractors and designers are the two types of most frequent BIM users, and overall support of BIM by clients/owners is limited, despite their increasing absorption of BIM related costs. Although there are an increasing number of disciplines involved in BIM use, the problem of insufficient inter-organizational collaboration, which is partly caused by institutional regulations on the use of traditional project delivery systems, still seems to be particularly acute in current BIM practices in China. This paper further illustrates that current BIM practices, in terms of both the extent of BIM use and client/owner support, are significantly associated with project characteristics. The results also illustrate that the majority of BIM uses in the surveyed projects have positive outcomes in terms of improvements in both task efficiency and task effectiveness in the design and construction processes, although the benefits associated with the improvement of task effectiveness are more substantial than those related to efficiency improvement. Based on a series of hierarchical regression analyses, this paper further provides support for the argument that project characteristics are influential in the success of BIM use; however, they show that the influences of the extent of integrated use and client/owner support are more significant. In the Discussion section, the paper also compares BIM practices and effectiveness in China with those in other regions.

As reported in similar studies worldwide [28,35,66], it is apparent that the well-known potential for BIM has yet to be fully exploited in the Chinese construction industry. There is a potential for greater benefits to be obtained by a more systemic and comprehensive use of BIM in a wider variety of application areas over the project lifecycle. To take full advantage of this would involve a shift in current thinking of the use of BIM in discrete applications to a more holistic approach involving reshaping the workloads and responsibilities of traditional project activities and the reallocation of risks and incentives among project participants. In doing this, and indeed as a precondition for such a transition, the current problems of interoperability among different BIM applications need to be further examined and addressed in terms of both technological interoperability and associated risk reallocation issues. To facilitate these changes, related institutional constraints on the use of more collaborative project delivery systems need to be addressed. Project clients/owners, especially those in public projects, should also be encouraged to play a more proactive role throughout the project lifecycle.

It should be noted that interpretation of the findings of this study is subject to several limitations. Firstly, the surveyed projects were not selected through a random sampling method. In order to improve the representativeness of the analysed projects, the samples were diversified with varied project sizes, natures, types and geographic locations. However, as better practices are more easily noticed by the industry and thus incorporated in this investigation, the extent of practical BIM use throughout the industry may be even lower than that shown within the surveyed projects. Secondly, with an intrinsic advantage of allowing replicability and thus enabling structured comparisons across different projects, a questionnaire survey was deployed as the main method to collect project-based data. This may generate potential problems of common method bias in the answers. However, this turns out to be less of a problem as Harman's one-factor test [69] showed that the single factor only accounts for 27.97% of the total variance in the measurements, indicating that common method bias is unlikely to be a substantial contaminant of the results. Thirdly, while the use of BIM is still developing worldwide, this study can only provide a temporal snapshot of the evolving practices in the specific context in China. With the further evolution of BIM use around the world, it will be worthwhile to extend the examination framework, especially in application areas, to further compare evolving BIM practices in different regions and generalise the research findings on how BIM benefits are influenced by related project and practice characteristics.

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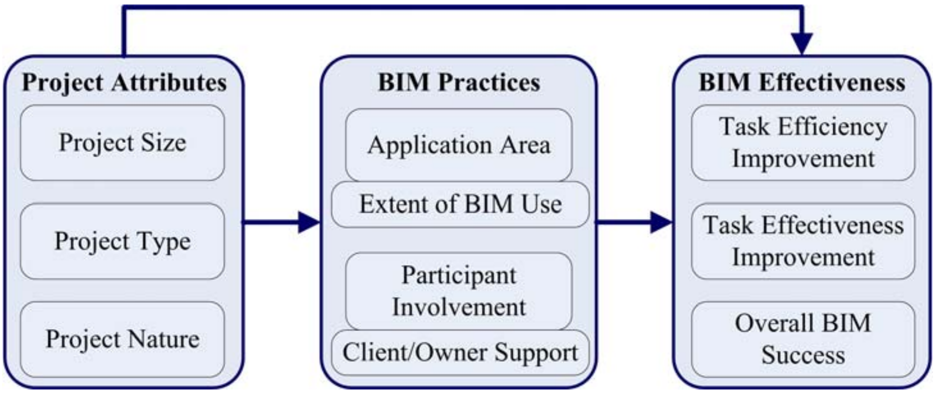

Figure 1 Conceptual research model

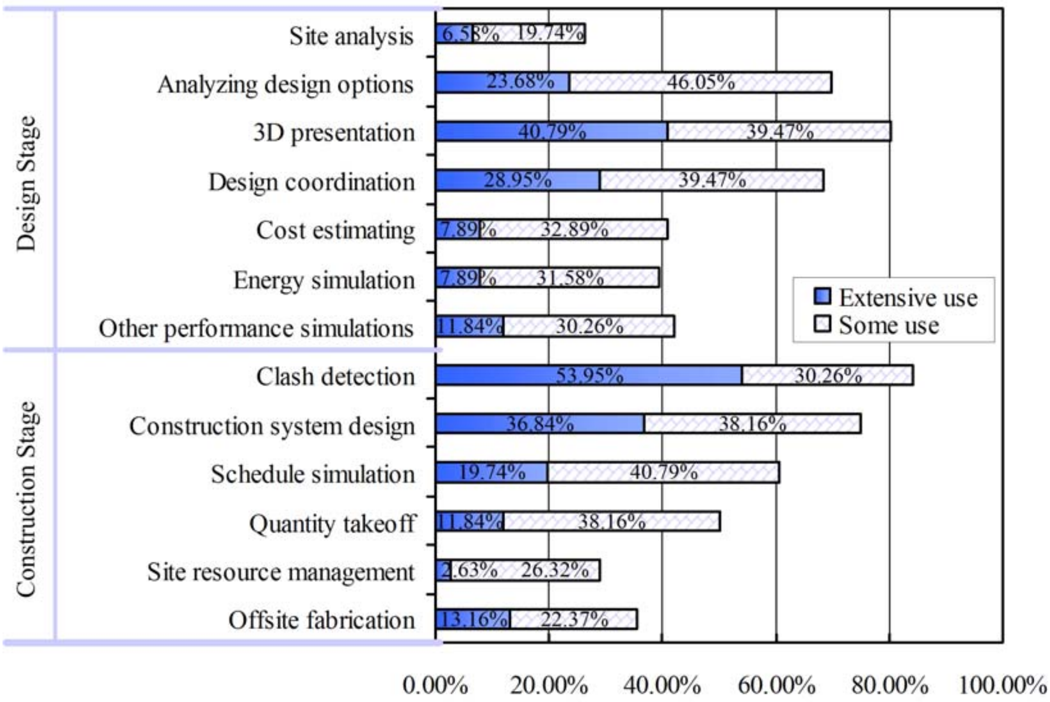

Figure 2 BIM practices in different application areas

Table 1
Project demographic information.

Variable	Category	Number	Percentage	Variable	Category	Number	Percentage
Year[a]	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[b]	94	88.7
Project nature	Public	50	47.2		EPC/DB[c]	10	9.4
	Private	56	52.8		Others	2	1.9

[a] Year for the commencement of construction activities.

[b] Design-Bid-Build.

[c] 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	[42,57]
	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	
Task efficiency improvement (TEY)	BIM facilitates the automatic and fast execution of design and construction activities	[35,58]
	BIM increases productivity in related design and construction processes	
	BIM saves time for project participants to conduct related design and construction activities	
Task effectiveness improvement (TES)	BIM reduces errors and rework in design and construction activities	[35,60]
	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	
Overall BIM success (OBS)	In terms of its overall impact on this project, the BIM use has been a success	[58,59]
	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	

Table 4

Validity measures and construct correlations.

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

[a] Composite reliability.

[b] Average variance extracted.

[c] 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[a]	R^2	F-value	p-value
Project size	0.211*	0.045	4.852	0.030
Project type[b]	0.203*	0.041	4.465	0.037
Project nature[c]	-0.054	0.003	0.306	0.582

[a] Standardized regression coefficients (β) are reported.

[b] Projects are dichotomously classified as residential and non-residential types: "1" represents residential project, "2" represents non-residential project.

[c] "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[a]	Mean	SD		SS[b]	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		

[a] To mitigate response bias, 14 responses from project clients/owners were excluded.

[b] 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[a]	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				

[a] D&C = design and construction.

Table 9

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

	TEY[a]			TES[a]			OBS[a]		
Variables	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[b]	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^2	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^2		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

[a] Standardized regression coefficients (β) are reported; N = 92, as 14 client/owner responses were excluded.

[b] Projects are dichotomously classified as residential and non-residential types: "1" represents residential project, "2" represents non-residential project.

* $P < 0.05$; ** $P < 0.01$.