Toward a Roadmap for BIM Adoption and Implementation by Small-Sized Construction Companies

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Abstract

Building Information Modeling (BIM) offers a variety of tools to help a wide range of stakeholders in the construction industry. There has been substantial research on the advantages and challenges of implementing BIM for large-scale construction projects; however, there is a dearth of research on the benefits and challenges faced by smaller construction firms when adopting BIM. Thus, this paper focuses on the cause-and-effects of BIM adoption in the construction industry. To achieve this objective, first, a literature review covering different aspects of BIM adoption was conducted. Second, large-sized construction firms who already have implemented BIM in several of their projects were interviewed through questionnaires. Based on the findings from the interviews, a set of survey questions was prepared and distributed among all types of construction firms to identify their innovativeness and level of BIM adoption. The survey contains company and demographics, innovativeness, and BIM-specific questions. Survey results show that small-sized construction companies are indeed far behind large-sized companies in respect to BIM adoption. This paper highlights the findings from the literature review and survey. Future research will take place to dive further into the survey data results and develop a roadmap that identifies a BIM function that can be adopted easily by small-sized construction companies.

Keywords

BIM • Innovativeness • Small-sized construction companies

105.1 Introduction

The nature of construction projects has become increasingly more complex; the complexity demands extensive planning, increased quality control, reliable communication, and constant collaboration. Roughly 90% of large-sized companies (more than 250 employees) are using Building Information Modeling (BIM) to some extent, while less than half of small-sized companies (fewer than 250 employees) are using it [16]. Advanced technologies have become available for use but are not being utilized as they have been in other industries. Roughly 50% of construction companies have reported spending 1% annually on technology; nearly 60% of construction companies are not considering any new technologies; and, 28.1% of these companies indicated that they do not bid on projects involving BIM [33]. Given that the construction industry is predominantly known as being traditionalists and more reluctant to adopt new developments, relative to other industries, it is crucial to explore the different explanations as to why that might be. This paper covers literature that discusses crucial BIM-related topics as well as preliminary survey data.

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105.2 Background

105.2.1 Innovativeness in the Construction Industry

Construction is continuously changing; the industry is plagued by insurmountable amounts of risk, a constant pursuit of improving sustainability, and increased complexity of designs. This changing industry is slow to embrace new technology. According to a survey conducted by Armstrong and Gilge [3], only 8% of the 218 senior executives participated are categorized as innovators, while 20% stated new technologies are "aggressively disrupting their business models." Gallaher et al. [8] noted that the problem in the construction industry is the continued paper-based business practices and the inconsistency of technology innovation.

Rogers [27] labels innovativeness as an excellent indicator of whether or not a company will be successful regarding implementing new technology into their current processes. According to Rogers [27], companies can be characterized into one of five categories: Innovators, Early Adopters, Early Majority, Late Majority, or Laggards (Fig. 105.1).

Innovators have the stability to manage successes and errors, as well as the financial resources, which are necessary due to the uncertainty that new technologies and software contain. From the survey conducted by Armstrong and Gilge [3], only 8% of the industry falls into this category. Early Adopters serve as role models to others. The Early Majority shows a willingness to adopt new technologies but are not the ones to lead the charge. The Late Majority represents the firms that only implement new technologies when it is an economic necessity. Laggards are the last individuals and companies to adopt new technologies after they are approved by the rest of the industry and have very low risk associated with them. The traditionalist mindset of these individuals and companies is the reason that their technology awareness is behind everyone else.

According to the Armstrong and Gilge [3], 69% of the construction industry are labeled as "followers" or "behind the curve;" similarly, Rogers would classify "followers" as the Late Majority and "behind the curve" as the Laggards.

Gholizadeh et al. [9] state that companies who want to stay competitive, regardless of size, need to invest in different applications of BIM and train their employees. Armstrong and Gilge [3] acknowledges that medium-sized construction companies, ranked by annual turnover ($1 to $5 billion), are the most innovative companies in the industry. The medium-sized companies credited this to the competitive advantage that technology provides; also, their manageable company size makes them more susceptible to adapt to new technologies and methods quickly.

Another management issue regarding innovation within the construction sector is merely the nature of the industry. According to Murphy [21], project management accounts for different constraints including problems with project objectives, regulatory requirements, and external factors. Project leadership often fails to address the management of newly available technology. Guo et al. [10] emphasize the need for implementing innovative management software throughout all phases of projects. Previous studies have developed successful theoretical processes involving innovative management; however, the majority of those studies do not provide practical tools for efficaciously implementing and managing those processes into construction projects [21].

105.2.2 The Effect of Workers' Age on New Technology Adoption

Previous studies suggest that the workers' age is not the reason for the lack of new technology implementation; instead, it is the workplace climate and how it is managed [22]. Though it should be noted, a study by Meyer [20] presents data showing that workers older than 30 years old can hurt the implementation of new technology. This is not surprising since workers

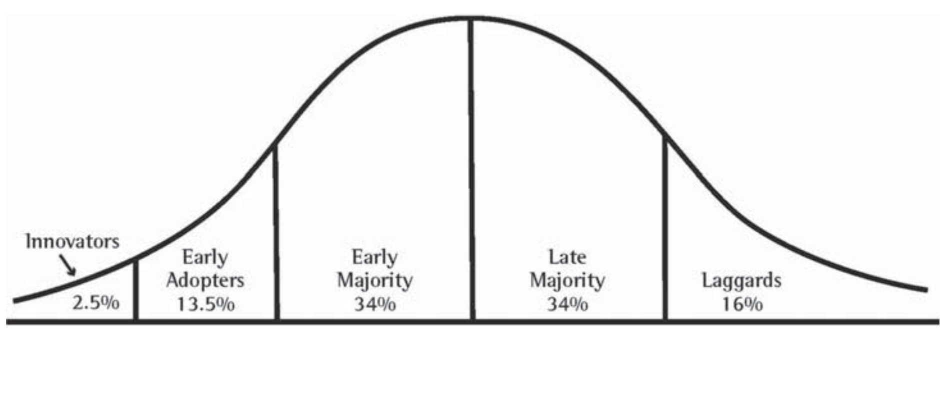

Fig. 105.1 Diffusion of innovation curve. Adopted from Rogers [26]

below the age of 30 have a higher potential and productivity rate regarding mastering new software [31]. Nonetheless, several other studies state that the innovativeness of the workplace has much more impact on the employee adaptiveness to new technology, compared to the age of the workplace [22, 20, 23].

105.2.3 BIM Applications in the Construction Industry

BIM is making a push as the new-age technology in the construction industry. Several studies have reported that BIM can improve the quality and efficiency of construction projects [13]. According to Forgues et al. [7], value engineering at the beginning of the design phase could result in a more cost-effective project delivery method, higher quality buildings, and increased control and predictability for the owner. BIM can increase the efficiency of the value engineering at the design phase if companies can manage the processes of the different applications. Hartmann et al. [13] examined seven commonly used BIM applications in the construction industry: photorealistic renderings, virtual design review, analyzing design options/building operations, analyzing construction operations, construction document production, bid package preparation, and cost estimating [33, 9]. This study focuses on photorealistic renderings, virtual design review, and analyzing construction operations. These functions were chosen due to their feasibility to be adopted by small construction companies.

Photorealistic Renderings: Virtual 3D models can be a potent tool for construction and architecture sales. Research conducted by Welsh [33] showed that 34.7% of companies that use BIM, use it for marketing presentations. Gholizadeh et al. [9] predicted that using BIM for facility space planning and logistics adoption would reach its peak by 2021.

Virtual Design Review: Having the ability to communicate design issues, clash coordination, and collaborate with other engineers without scheduling an in-person meeting can save time and money. Traditionally, different trades would meet and discuss designs over 2D drawings. BIM enables multiple design models to be combined, which then can be automatically checked for clashes using BIM supporting tools, such as Autodesk Navisworks or Tekla BIMSight. Gholizadeh et al. [9] showed that clash detection was the second most-adopted BIM function [16, 33, 7, 12]. Sixty-three percent of companies use BIM for clash detection [33].

Analyzing Construction Operations: The analysis of construction operations is the most widely used application, according to Hartmann et al. [13]. Gholizadeh et al. [9] agree with Hartmann, showing that constructability analysis is the third-most adopted application. BIM tools such as Synchro Pro or Navisworks can be used to combine the 3D building models with the project schedule. The result is a time-stamped 3D model, which enables visualization of construction sequencing. Having the opportunity to track and visualize the project process can be a potent tool for project managers to make crucial decisions [4]. Being able to see the logistics of the project allows project teams to identify any issues with the sequencing of the construction.

Having superior technical support is necessary when linking different software with BIM due to the interoperability challenges [4, 2]. Nevertheless, Porwal and Hewage [24] stated that the most significant challenges of implementing BIM are the organizational and people-centered problems [4, 28]. The technology itself can better the construction industry, but it cannot be utilized if the management is not willing to create a well-put-together process.

105.2.4 Trade Specific BIM Applications

There is a shortage of studies that explore trade-specific BIM tools. The mechanical, electrical, and plumbing (MEP) industry is the only sector of the construction industry that has a substantial amount of research. The following subsections explore different projects and BIM tools that are trade specific.

MEP Construction. MEP construction has been the focal point for BIM use [16]. As previously mentioned, 63.5% of companies rely on BIM for coordination and clash detection, which is done by using AutoCAD MEP or Autodesk Navisworks; used by 23.4 and 15.9% of companies, respectively [33]. These tools can merge BIM models are automatically detect clashes. Specialty trades' management can then manage clashes [7]. Fixing potential clashes before the construction starts has been the reason for many companies implementing BIM [16].

Steel Construction. Tekla Structures software provides steel detailers, fabricators, and erectors with many tools that enhance management and constructability. Some of Tekla's tools include model design, estimating, detailing, and field visualization [32]. Models can be created for all types of construction ranging from stadiums to bridges. Tekla Structures has been a reliable tool for the Mercedes Benz Stadium project, a $1.5-billion Leadership in Energy and Environmental Design—platinum certified stadium [32].

The Barclays Center project, in Brooklyn, New York, was almost entirely engineered utilizing BIM models. The architectural firm used Revit for design, the engineering firm used Tekla Structures to model the structural steel system, and then the structural model was distributed to all of the subcontractors to work on [17].

Concrete Construction. Different technologies including laser scanners and total stations are used to add information to BIM models [22–25]. By using these technologies, as-built data can be captured as soon as activities are finished. Using BIM models for quality assurance and quality control has proved to be more accurate and efficient in concrete construction [14]. For concrete, as-built BIM models can reduce rework; therefore, save time and money. Using BIM to document location in-concrete components helps mitigate rework and, most importantly, improve workers' safety [25]. For example, the locations of post-tension cables can be inputted in the BIM model and then can easily be located after the concrete is poured.

Fire Protection. A ubiquitous component that is commonly left out of the clash detection discussion is fire protection systems. The International Building Code (IBC) has many regulations that fire protection systems must abide [15]. The power of BIM allows designers and engineers alike to give each component of active and passive fire protection systems characteristics. Another element that gets left out of clash detections is walls. Fire-resistant walls are highly regulated by the IBC, which causes many issues with their location, concerning the other systems of the building. BIM also allows facility managers to remotely access the type of fire protection equipment that may need maintenance from the model [29].

105.2.5 Effect of Project Delivery Method on BIM Implementation

According to Porwal and Hewage [24], no specific project delivery method is best suited for implementing BIM to a project. Although, the integrated project delivery (IPD) method that has worked well with BIM integrated projects. The traditional project delivery methods, such as Design Bid Build (DBB) tend to separate the design and construction phases, which is detrimental to the communication between teams [4, 24, 19].

***Design-Bid-Build* (DBB)**. In DBB project delivery, the owner, designer, and constructor are all separate entities, which results in poor constructability and ultimately increased project costs, value engineering, as well as an ineffective transfer of information between project parties [24, 5, 6]. Although BIM enables collaboration and communication among stakeholders, the DBB method does not allow project teams to form until post-bidding. Gholizadeh et al. [9] showed that 38% of BIM users and 58% of non-BIM users worked on projects delivered via DBB.

Design-Build (DB) and Construction Manager/General Contractor (CM/GC). DB method is growing in popularity due to its ability to reduce project costs and improve project schedule and construction quality [4, 5]. Since the designer and the constructor are one entity, BIM can be more effectively utilized for constructability and value engineering [4, 28]. Projects with a construction manager also promote the use of BIM due to the increased communication between stakeholders. Both DB and CM/GC methods allow projects to be fast-tracked in owner's favor.

Integrated Project Delivery (IPD). This project delivery method forces the project stakeholders to communicate and make decisions together resulting in enhanced collaboration and better-quality projects. According to Zhang and Guangbin [34], one of IPD's characteristics is that it can fully utilize the technological capabilities of a project; therefore, IPD is a BIM-friendly project delivery method because BIM and IPD promote many of the same characteristics [28, 19, 6].

Three most commonly used project delivery methods were discussed above to understand better the circumstances of using BIM. Conclusively, the owners, managers, designers, and contractors must be able to work as a team to successfully construct a project. For BIM to be successful, not only do previous processes need to be changed, new procedures for each of the BIM functions need adoption and implementation [4, 28].

105.3 Methodology and Data Collection

To further explore the advantages and limitations of BIM in the construction industry, 800 surveys were sent out to companies located predominately on the West Coast of the United States. Out of the 800 surveys, 83 ($\sim$10%) participated in the survey. Companies completed the survey voluntarily and uncompensated. The survey was not limited to any types of construction companies, due to comparative reasons.

The data collection was broken down into two components: preliminary interviews and an official survey. The preliminary interviews were informal. Two companies that used BIM were interviewed through a questionnaire to gain more knowledge about how BIM was being perceived in the industry. The information gained from these interviews and a literature review were then used to develop a survey consisting of sixteen questions. The survey questions can be divided into three main categories: (1) company demographics, (2) innovativeness, and (3) BIM-related questions.

The essential demographics of the survey participants are listed below:

- 37% of the companies are small-sized (<250 employees).
- 63% of the companies are general contractors.
- 76% of the companies currently use BIM.
- 83% of the companies claim to be ahead of the majority of the industry or be one of the first to adopt and implement new technology in the industry.

The basis of this study focuses on comparing small-sized construction companies to large-sized construction companies to determine similarities and differences. The threshold of company size is based on findings in a SmartMarket Report, where companies with less than 250 employees were considered small [18]. Once the similarities and differences between small and large sized companies are identified, an appropriate BIM function will be chosen, and an adoption roadmap will be developed. The adoption roadmap will be customized for practical use and sent out to construction industry professionals to be verified. If necessary, modifications will be made to the adoption roadmap by using Delphi method [11]. The results presented in this paper highlight the critical findings from the survey.

105.4 Results

The data collected from the survey is analyzed under the following sections: (1) Company size (number of employees) and average annual budget, (2) innovativeness, and (3) the potential and risks of BIM. The survey presented company size and average annual budget in ranges that allow the researchers to classify company size.

The survey results show that large-sized companies (Table 105.1) use BIM technologies at a higher rate compared to small-sized companies (Table 105.2). It should be noted that large-sized companies also have a higher average annual budget; similarly, of the 33 companies with an average annual budget of less than $150 million, 16 (~48%) of them used BIM.

The survey asked participants to evaluate the rate at which their company uses the following tools: Microsoft Suite, Bluebeam, AutoCAD, Revit/Tekla Structures, Synchro PRO, and NavisWorks. Microsoft Suite was used most often on a daily basis (~93%), followed by Bluebeam (~88%), while Synchro PRO was only used daily by 8 companies (~9%). Interestingly, the three tools that are not being used at all are Synchro PRO (~61%), Navisworks (~30%), and Revit/Tekla Structures (~24%). BIM technology has significantly increased in the workplace. Only two companies were using BIM before 1995, while 56 have used it before 2016. It should be noted that five companies state they do not use BIM anymore but have used it before 2017. Of the 20 companies that do not currently use BIM, 13 (65%) of them plan on adopting it in the future.

Tables 105.3 and 105.4 report the potential and risks, respectively, when deciding to implement BIM. Company productivity (~65%) and cost benefits (~65%) had the highest amount of potential when deciding to adopt BIM. Technical issues (~41%) and the implementation process (~36%) of BIM were associated with a high amount of risk.

Table 105.1 Large-sized companies' average annual budget

Large-sized companies (more than 250 employees)							
Average annual budget (millions)							
	Less than $50	$50–$100	$150–$250	$250–$400	More than $400	Total	BIM (%)
General contractor	1	3	1	3	23	31	27/87
Engineering firm/consultant	0	0	1	0	2	3	3/100
Specialty contractor	1	2	4	4	4	15	15/100

Table 105.2 Small-sized companies' average annual budget

Small-sized companies (less than 250 employees)							
Average annual budget (millions)							
	Less than $50	$50–$100	$150–$250	$250–$400	More than $400	Total	BIM (%)
General contractor	9	5	3	2	0	19	10/53
Engineering firm/consultant	1	0	0	0	0	1	1/100
Specialty contractor	10	1	0	0	0	11	5/45

Table 105.3 BIM potential during the decision to adopt

BIM potential during the decision to adopt							
	Negative	None	Low	Mild	High	Exceptional	Total
ROI	3	5	8	13	30	7	66
Company productivity	1	5	2	10	43	5	66
Proposal acceptance rate	0	6	10	22	23	5	66
Schedule benefits	0	5	6	16	31	8	66
Cost benefits	1	5	2	10	43	5	66
Total	5	26	28	71	170	30	

Table 105.4 BIM risks during the decision to adopt

BIM risks during the decision to adopt						
	None	Low	Mild	High	Exceptional	Total
Cost (initial investment, ROI, maintenance, etc.)	3	19	25	15	3	65
Contractual issues (liability, risk, ownership of model, etc.)	5	27	24	8	1	65
Technical issues (learning curve, interoperability, etc.)	3	11	23	27	2	66
Implementation process	3	4	31	23	3	64
Total	14	61	103	73	9	

105.4.1 Limitations and Further Research

The limitation of this research is the diversity of the survey. The survey was only distributed to the companies based on the West Coast of the United States. Currently, the research team is working on distributing the survey to Midwest construction companies to obtain a more diverse sample size.

In future research, a more in-depth statistical analysis will be conducted on a more diverse and large dataset to ensure the accuracy of the similarities and differences between small and large-sized construction companies. As mentioned previously, choosing a BIM function and developing an adoption roadmap is the primary goal of this research.

105.5 Conclusions

This paper presented the results from a literature review and survey obtained from 83 construction companies. The results showed that the number of construction companies that utilize BIM technologies has undoubtedly increased within the last decade, but the small-sized construction companies are falling farther and farther behind large-sized companies. The ultimate goal of this study is to identify the BIM function that can be readily adopted by small-sized construction companies and develop a roadmap for them to adopt BIM at the same rate as large-sized companies. By doing so, small-sized construction companies can stay competitive and relevant within the industry. In future research, a roadmap will be developed by combining the knowledge gained through literature review, interviews, and survey analysis to encourage small construction companies to explore the advantages of BIM.

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