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A DECISION-MAKING ALGORITHM FOR SELECTING BUILDING INFORMATION MODELING FUNCTIONS

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Abstract: Due to a lack of common financial benchmarking for various BIM functions, decisions regarding adopting BIM functions are usually made based on market pressure or a manager's intuition. While larger firms can afford such a trial and error process, the cost burden on small- to medium-sized firms is significant. Therefore, there is a need to assemble the tacit knowledge of BIM users into a simple algorithm that can aid new users in understanding the advantages and disadvantages of implementing BIM functions in a project. This study aims to develop a decision-making algorithm that helps practitioners choose BIM functions for their project to maximize success. Some of the independent variables that were considered are project category, project size, delivery method, and time of involvement of different parties. A questionnaire was developed to measure the importance of these variables on using different BIM functions. The survey was sent out to 3,017 owner representatives, architects, and project managers. In total, 119 individuals responded to the survey of which 81 were BIM users. The analysis of the data resulted in a decision matrix and an algorithm that provides guidance for decision makers regarding adopting different BIM functions. Most of the respondents worked in the building and commercial construction sector, which likely influenced the respondents. The findings of the study have contributions to both academia and practice. The results can be used by researchers as a benchmark for future studies and practitioners can use the decision-making algorithm to select an appropriate BIM function for their projects.

1 INTRODUCTION

The potential of building information modeling (BIM) to unify the traditionally fragmented AEC industry has contributed to BIM gaining wide acceptance in the North American market (Bynum et al., 2013). BIM has fostered closer collaboration by enabling interaction and aiding collective understandings of projects (Grilo and Jardim, 2010; Hanna et al., 2013). In doing so, BIM has been simultaneously expanding and advancing in its applications. The Smart Market series (McGraw-Hill, 2008; 2009; 2012) provides a comprehensive understanding of the adoption pattern of BIM among various construction sectors and disciplines in the AEC industry. Per the McGraw-Hill report (2012), the industry adoption rate of BIM in North America has shown a noteworthy increase, from 28% in 2007 to 71% in 2012. The report also indicates that there has been a steady increase in BIM adoption within various disciplines, especially among mechanical, electrical, plumbing, and structural engineers. However, despite BIM enabling the construction industry to merge via a virtual process (Azhar, 2011), limitations and challenges to the expansion of this approach still exist.

The ongoing challenges to BIM mainly exist in the realms of technical, contractual, and personal relationships among construction professionals (Hamdi and Leite, 2014). BIM-enabled projects continue to be organizationally divided (Dossick and Neffe, 2009), and on average 25% of construction industry professionals refuse to use BIM for various reasons. Some reasons contributing to lower usage of information and communication technologies (ICT's) like BIM are identified in literature review as technical and financial problems, attachment to conventional ways of conducting business (Doherty, 1997; Samuelson, 2002), and the lack of an effective tool for the entire construction market (Egbu and Botterill, 2002). Another challenge encountered by BIM is the low adoption rate among small and medium enterprises (SME's). Studies indicate that despite ICT's being a means for instant knowledge transfer, few SME's can use such innovations to their full capacity (Acar et al., 2005) and most SMEs fail to adopt and implement them (Blackley and Shepard, 1996; Acar et al., 2005).These findings are reflected in the fact that the adoption rate of BIM is only 49% among small firms as compared to 91% in large firms (McGraw-Hill Report, 2012).

Very few studies—McGraw-Hill series reports (2008; 2009; 2012) and Krieder et al., (2010)—have attempted to evaluate the value and the frequency of use of various BIM functions across disciplines and project phases. Due to a lack of common financial benchmarking for various BIM functions (Becerik-Gerber and Rice, 2010), decisions regarding adopting BIM functions are usually made based on market pressure or a manager's intuition. While larger firms can afford such a trial and error process, the cost burden on small- to medium-sized firms is significant. Therefore, there is a need to assemble the tacit knowledge of BIM users into a simple algorithm that can aid new users in understanding the advantages and disadvantages of implementing BIM functions in a project. To address this need, this study aims to develop a decision-making algorithm that helps practitioners choose BIM functions for their project to maximize their success.

This study begins by conducting a literature review to identify relevant BIM functions and independent variables that can be used in the decision-making process when selecting which of these functions to use in early stages of a project. An online survey is conducted to gather the tacit knowledge of existing BIM users. Descriptive statistics are then used to present the findings. An easy-to-use algorithm is developed based on the independent variables. The results of this study project a novel tool that can be further enhanced for accuracy. This study will benefit future researchers seeking to understand the factors contributing to the implementation of BIM functions. It will also aid construction professionals in the decision-making process while they select the appropriate BIM functions.

2 LITERATURE REVIEW

The wide acceptance of BIM could be partly accredited to the growing number of applications that appeal to various disciplines in the construction industry. Therefore, an extensive list of BIM functions can be found in literature. Since inception, collaboration has been one of the key characteristics of BIM (Eastman et al., 2011). 3D visualization and clash detection are two major functions of BIM that aid effective communication and interdisciplinary understanding among multiple disciplines (Eastman et al., 2011). Apart from these two functions, BIM has shown high potential for use in several other construction processes and has rapidly advanced in its number of applications in the past decade. Currently, BIM encompasses the most integral processes in construction, namely scheduling, constructability analysis, structural analysis, the shop drawing process, cost estimation and quantity takeoff, facility space planning and logistics, material-tracking delivery and management, stakeholder engagement, project turnover and closeout, code validation, energy analysis, and facility management.

Prior to use of BIM, studies (e.g., Chau et al., 2004) presented a 4D visualization model by linking 3D geometric model with scheduling data. Chau et al. (2004) presented the potential benefits of 4D visualization as a means of facilitating site planning and management, predicting the occurrence of any potential site problems, and streamlining site management practices. Even though 4D visualization models presented several advantages over the traditional 2D CAD process, the process remained tedious and lacked the significant feature—change management—that BIM later introduced. Tulke et al.

(2008) suggested integrating construction scheduling in a collaborative, BIM-based design process by establishing quantity takeoff as a model-based central approach prior to scheduling and cost estimation. However, even though benefits of BIM were well-documented for construction-management work—like scheduling—the application's use was reported as infrequent (Goedert and Meadati, 2008).

Another important process in construction benefited by BIM is constructability analysis. Constructability analysis is a preconstruction process that identifies potential obstacles during construction and thus helps prevent delays and cost overruns (Pulaski and Horman, 2005). Sulankivi et al. (2014) discusses six promising ways of using BIM to improve constructability: visual examination of BIM, clash detection using a combined model, BIM-based construction planning, visualization in 3D or 4D, BIM as a tool for cooperation, and BIM-based checking, analysis, appraisal, and measurement of safety or constructability. Despite the benefits named in literature, very few studies have investigated the use of BIM for constructability.

In contrast to the inadequate research regarding several BIM functions, in the past few years, two BIM functions have been extensively discussed namely facility management and energy analysis. Facility management has evolved from being a practice to a profession. As defined by IFMA (2004), facility management is a multidisciplinary profession that integrates people, places, processes, and technology during the operations and maintenance (O&M) phase to assure the smooth functioning of the build environment. The O&M phase demands extensive information from multiple disciplines (Caldas et al., 2005). This information is provided by contractors to the facility managers in the form of a pile of project documents in various formats (William East et al., 2013), all of which need to be manually fed into the maintenance management software. BIM has the capability to eradicate this cumbersome process. Becerik-Gerber et al. (2012) identified ten potential application areas for BIM in facility management: locating building components, facilitating real-time data access, visualization and marketing, checking maintainability, creating digital assets, space management, planning and feasibility studies for non-capital construction, emergency management, controlling and monitoring energy, and personnel training and development. However, along with the numerous potential application areas, implementation of BIM for facility management also faces numerous challenges. Seven barriers to implementing BIM in facility management—as identified by Becerik-Gerber et al. (2012)—are: unclear and invalidated benefits of BIM, increase in the amount of work, lack of interoperability, lack of demand by owner community, lack of clarity about responsibility in contracts, lack of standardization in facility management tools, and lack of experience in using BIM. Even though there has been a lot of research related to BIM and facility management, to-date, the adoption of BIM in facility management is slow (Brooks and Lucas, 2014).

Energy analysis is another application discussed extensively in the literature, likely due to the increasing importance of sustainable construction. Considering buildings' huge share in energy consumption, having an efficient energy analysis tool that is easy to run and easy to understand could empower designers to make more energy-conscious decisions during the early design phase (Kim and Anderson, 2013). BIM has been found to have the potential to aid energy analysis to ensure optimized, sustainable building designs (Krygiel and Nies, 2008; Azhar et al., 2011; Kim and Anderson, 2013; Bynum et al., 2013). However, upon investigating the perceptions of designers and constructors on using BIM for sustainability, Bynum et al. (2013) found that most of their survey respondents believed that sustainability was not a primary application of BIM; they also found that problems with interoperability continue to persist among the various BIM applications in the industry.

Our literature review concludes that although several studies have investigated the role of BIM functions individually and have offered unique objectives as part of their investigations, very few studies have attempted to evaluate the advantages and disadvantages of implementing BIM functions in a project.

3 METHOD OVERVIEW

To achieve the objective of the study, first the study attempted to explore factors impacting the decisions of using BIM functions within the construction industry. An in-depth literature review was conducted to identify fourteen relevant BIM functions shortlisted after expert opinion. The identified BIM functions formed the basis of inquiry for each of the independent variables investigated. A comprehensive questionnaire was developed and distributed to 3017 construction professionals via an e-mail that contained the project description and a link to the survey. The e-mail addresses of contacted individuals were extracted from the publically accessible member lists of Associated General Contractors (AGC) and Associated Builders and Contractors (ABC) organizations from eleven states of North America (Iowa, Illinois, Hawaii, New Mexico, Nebraska, Washington, Florida, Arkansas, Arizona, New York and Maine); though the limited public access added a geographical limitation to the findings of the study. In an attempt to reach maximum audience, the participants of the 2012 Design-Build Institute of America (DBIA) conference were also approached. The questionnaire link was also posted on the LinkedIn page for the American Society of Civil Engineers. Participation in the survey was voluntary.

The objective of the questionnaire was to understand whether BIM is required for all projects and whether project-delivery method and team selection impacts the decision to use BIM in projects. For those projects in which BIM is required, this questionnaire also examined which functions should be used based on the project's size (Refer Table 1) and objectives (i.e., cost, time, quality, and owner satisfaction). The questionnaire contained two sections. First, a personal experience and information section that sought to identify the participant's professional background; to increase participation and encourage open expression of opinion, this section did not require any contact information (e.g., name, e-mail addresses). The first section ended with a key question regarding whether or not the participant had used building information modeling for their projects. In the second section—the BIM users' section—participants were provided with a description of every BIM function. The Likert scale ranging 1 (low) to 6 (High) was used to inquire about frequency, difficulty, and perceived value for each BIM function. The scale also provided an option called '*I don't know'* for respondents unfamiliar with a certain function or unknowledgeable about a question. The survey was conducted for a period of one month, during which time two reminders were sent to each of the recipients. This study uses descriptive statistics to present the findings. Based on these findings, the study develops a decision matrix and an algorithm that provides guidance for decision makers regarding adopting different BIM functions. Based upon the independent variables, this study uses descriptive statistics to present the findings and develops an easy-to-use algorithm to translate the findings into a tool for new BIM users.

Table 1: Project Size

Project Size	Range
Very Small (VS)	Less than $100,000
Small (S)	$100,000 to $1Million
Medium (M)	$1Milion to $10Million
Large (L)	$10Million to $100Million
Very Large (VL)	Greater than $100Million

4 RESULTS

Of the 158 responses received, all partial responses were excluded from the analysis to maintain consistency in results. This yielded a response rate of 3.9% with 81 responses from BIM users and 37 from BIM non-users.

4.1 Participant Background

The analysis indicated participation of all targeted divisions of construction professionals in the survey. In total, 69% of respondents were BIM users and 31% were BIM non-users. Majority of respondents held a managerial position (87%) with the average work experience of participants as 26 years. Among BIM users, majority of the participants indicated their project categories as medium and large; and employed design-bid-build and design build as the project delivery method for most projects on average. Among BIM non-users, majority of the participants indicated their project categories as small and medium; and employed design-bid-build as the project delivery method for most projects on average. Most of respondents among BIM users (30%) stated to be multi role organizations with half the respondents identifying as DB+CM/GC, while majority of respondents among BIM non-users (39%) stated to be owners. The findings indicate that a total of 72.5% of respondents think that BIM is not required for all the projects which highlights the importance of developing decision making algorithm for selecting right BIM function for a project.

4.2 Descriptive Statistics

The project delivery methods used in construction projects determine the organizational relationships and have been found to influence project outcomes and processes (Beard et al. 2001). To investigate the role of project delivery methods in facilitating successful adoption of BIM, the questionnaire asked respondents to provide a rank order for each. The Design Build (DB) delivery method was found to play the most significant role in facilitating successful adoption of BIM followed by Integrated Project Delivery (IPD) method. Design Bid Build (DBB) was ranked at the bottom. For project procurement methods, 2-Stage RFP was ranked at the top in facilitating successful adoption of BIM, followed by Pre-Qualified Bid, Sole Source, 1-Stage RFP and Low Bid (Refer Table 6). Upon inquiring about prefabrication, respondents indicated that on average a minimum of 24% of prefabrication is required in a project to benefit from BIM.

The questionnaire inquired about the minimum project size required for implementation of each of the listed BIM functions. The findings indicate that a total of 72.5% of respondents think that project size impacts the decision of using BIM functions. As shown in Table 2, more than 75% of participants believe that the minimum project size for employing 3D visualization, clash detection, constructability analysis, structural analysis, cost estimation and quantity take off and; stakeholder engagement is 1 million to 10 million (Medium size project). While more than 50% participants believe that minimum of medium size project is required for employing any of the fourteen BIM functions listed.

Table 2: Minimum project size required to have a significant impact on project success

	VS	S	M	L	VL	Number of users
3D Visualization	21%	52%	86%	100%	100%	80
Clash Detection	9%	30%	80%	98%	100%	75
Facility Space Planning and Logistics	15%	23%	67%	94%	100%	47
Code Validation	14%	21%	67%	93%	100%	17
Constructability Analysis	12%	32%	80%	96%	100%	56
Structural Analysis	10%	27%	75%	98%	100%	35
Cost Estimation & Quantity Take-off	8%	30%	76%	98%	100%	50
Scheduling (4D Animation)	4%	10%	50%	96%	100%	45
Energy Analysis	7%	20%	74%	98%	100%	27
Shop-drawing Process	9%	28%	72%	87%	100%	55
Material Tracking, Delivery and Mgt.	4%	13%	48%	85%	100%	17
Stakeholder Engagement	20%	35%	84%	98%	100%	50
Project Turnover & Closeout	6%	19%	66%	94%	100%	39
Facility Management	9%	13%	67%	98%	100%	21

More than half (59.26%) of the respondents indicated that project objective impacts the decision of using BIM functions. Four project objectives were investigated in this study - reducing project cost, reducing project time, improving quality and, improving owner's satisfaction (Table 3). Findings indicated that clash detection was the only BIM function among the fourteen BIM functions investigated that had a high impact on all four project objectives.

5 ALGORTIHM FOR SELECTING BIM FUNCTIONS

Using the results of the study, an algorithm is developed to aid practitioners choose BIM functions for their project to maximize success. The algorithm is limited to the fourteen BIM functions discussed in this study and is based on the following assumptions: (1) decision to use/not use BIM in a project is a function of the project delivery method and team selection; (2) selecting different BIM functions depends on the project size and project objectives; (3) the project objectives that determine applicability of a BIM function are cost, schedule, quality, and owner's satisfaction. Based on these assumptions, the research team developed a decision making algorithm that consists of four major steps. These steps are explained in more details below.

Table 3: Impact on reducing project cost and time and; improving quality and owner's satisfaction*

	Reducing		Improving	
BIM functions	Project Cost	Project Time	Project quality	Owners satisfaction
3D Visualization	4	4	5.5	6
Clash Detection	6	6	6	5
Facility Space Planning and Logistics	4	4	4.5	5
Code Validation	3	4	4	4
Constructability Analysis	5	5	5	4
Structural Analysis	5	5	5	4
Cost Estimation & Quantity Take-off	4	4	4	4
Scheduling (4D Animation)	4	5	4	5
Energy Analysis	4	3	5	5
Shop-drawing Process	4	5	5	4
Material Tracking, Delivery and mgt	3	5	3.5	4
Stakeholder Engagement	5	4	5	6
Project Turnover & Closeout	4	3	4	6
Facility Management	4	3	4	6

* Impact measured by a Likert Scale, with 1 = Very low and 6 = Very High

Step 1: Project delivery and procurement method

Studies have found project procurement and project delivery methods to have varying impact on success of BIM (Becerik-Gerber and Rice, 2010). Integrated project delivery (IPD) (Becerik-Gerber and Rice, 2010; Azhar, 2011) and Design-Build (DB) are cited as the most effective project delivery methods in facilitating the use of BIM (Bynum et al., 2013). Also, procurement methods are found to be crucial in identifying the key issues while developing a BIM contract (Chunduri et al., 2013). Thus, in the first step of the algorithm we identify combinations of project procurement and project delivery methods eligible for achieving BIM benefits. The research team suggests that for the following combinations of the project delivery method and team selections, BIM provides the most benefits for project stakeholders: DB and 2-Stage RFP; DB and Pre-Qualified Bid; DB and Sole Source; CMR and 2-Stage RFP; CMR and Pre-Qualified Bid; IPD and 2-Stage RFP; IPD and Pre-Qualified Bid; and IPD and Sole Source. In the first step, the decision maker checks whether the project has any of the above mentioned delivery and team selection combinations. If the combination is right, using BIM would be beneficial for the final project success.

Step 2: Project size

While selecting a BIM function, the most frequent question raised by a novice BIM user is about the project size (Won et al., 2013). Upon investigating whether or not the project size impacted the decision of BIM implementation, 72.5% respondents complied. The findings also indicated that the ratings for BIM functions differed as per project size. Thus, in the second step, the algorithm classifies the use of BIM function as per project size. The results of the survey indicated that BIM functions are not required for very small projects. On the other hand, BIM functions can be beneficial for large and very large projects. Therefore, the size of a project can be differentiator when one is comparing a small ($100,000 to $1Million) and medium ($1Milion to $10Million) size project. In the algorithm proposed in this study, the ratings provided by experts for project size will be used as modification factor for the contribution of a BIM function (M_j). For example, 3D Visualization potential contribution into a small size project should be multiplied with 52% while in a medium size project it should be multiplied with 86% (Table 4).

Step 3: Project objectives

Another factor that plays a significant role in determining the applicable BIM function for a project is the relative weight of project objectives (W_k). These weights will be used later to be multiplied with the contribution of a BIM function to achieve the objective (S_{kj}) obtained from the survey and summarized in Table 3. The ratings scale from Table 3 is converted to percentage for uniformity (Table 4).

Table 4: Project size and objectives scores for different BIM functions

	Project objectives				Project size	
BIM functions	Cost (1)	Time (2)	Quality (3)	Owners Satis. (4)	S (5)	M (6)
3D Visualization	67%	67%	92%	100%	52%	86%
Clash Detection	100%	100%	100%	83%	30%	80%
Facility Space Planning and Logistics	67%	67%	75%	83%	23%	67%
Code Validation	50%	67%	67%	67%	21%	67%
Constructability Analysis	83%	83%	83%	67%	32%	80%
Structural Analysis	83%	83%	83%	67%	27%	75%
Cost Estimation & Quantity Take-off	67%	67%	67%	67%	30%	76%
Scheduling (4D Animation)	67%	83%	67%	83%	10%	50%
Energy Analysis	67%	50%	83%	83%	20%	74%
Shop-drawing Process	67%	83%	83%	67%	28%	72%
Material Tracking, Delivery and mgt	50%	83%	58%	67%	13%	48%
Stakeholder Engagement	83%	67%	83%	100%	35%	84%
Project Turnover & Closeout	67%	50%	67%	100%	19%	66%
Facility Management	67%	50%	67%	100%	13%	67%

Step 4: Prioritizing BIM functions

After identifying the weight of project objectives, one can calculate the potential contribution that each function can provide for the project using the following equation:

$$C_j = \sum_{k}^{\substack{All \\ Objectives}} (W_k \times S_{kj}) \times M_j$$

In which C_j is the contribution of a BIM function j to the overall success of the project; W_k is the relative weight of objective k for the project; S_{kj} is the contribution of a BIM function to the objective k (Table 4; columns 1 to 4); M_j is the modification factor related to project size (i.e. medium and small) for BIM function j (Table 4; columns 5 and 6). By calculating the potential contribution of each BIM function, one can select most beneficial BIM functions for a project. Flowchart of the proposed process is shown in Figure 1.

To demonstrate practicality of the process, one can consider a project with the following characteristics: assume that the a medium size DB project is procured using 2-Stage RFP and cost and quality are the main project objectives with relative weights of 0.80 and 0.20 respectively. The potential contribution of BIM functions are presented in Table 5 and sample calculations for the contribution of clash detection is provided below:

$$C_{Clash\ Detection} = \sum_{k}^{Cost\ \&\ Quality} (W_k \times S_{kj}) \times M_j$$

$$= \sum (W_{Cost} \times S_{Cost\ \&\ Clash\ Detection} + W_{Quality} \times S_{Quality\ \&\ Clash\ Detection}) \times M_{Clash\ Detection}$$

$$= \sum (0.8 \times 1.0 + 0.2 \times 1.0) \times 0.8 = 0.8$$

As one can see in Table 5, clash detection (contribution score = 80%), stakeholder engagement (contribution score = 70%), constructability analysis (contribution score = 67%), structural analysis (contribution score = 63%), and 3D Visualization (contribution score = 62%) have the highest priority to be implemented in the project.

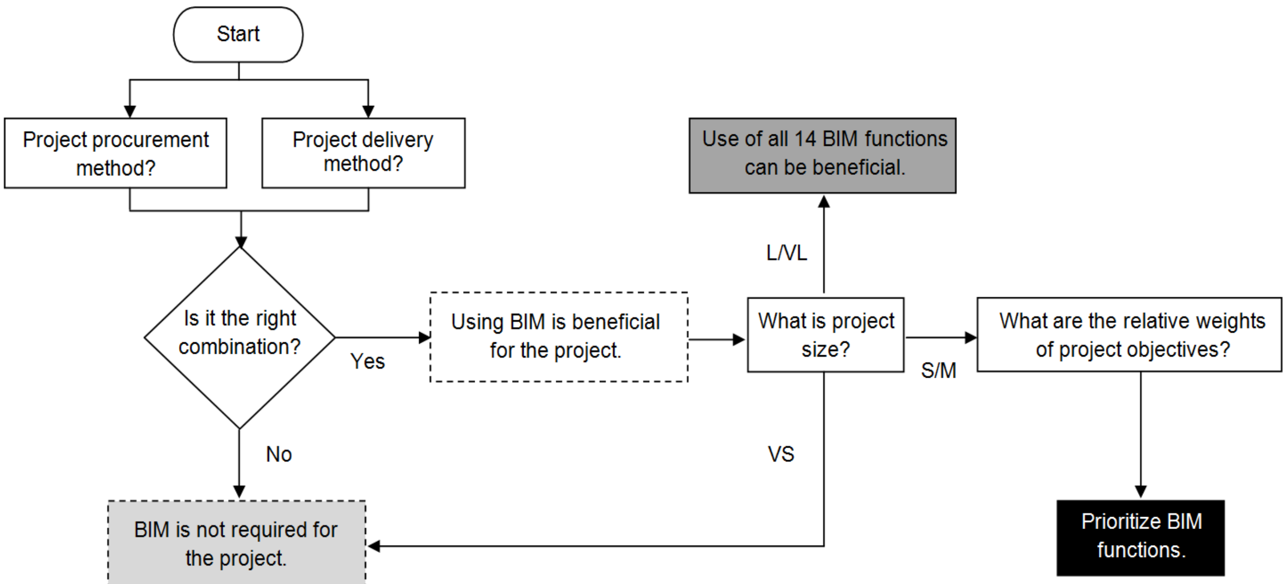

Figure 1. Decision making flowchart of selecting and prioritizing BIM functions

Table 5: Potential contribution score calculated for a hypothetical project (size=medium; weight of cost=0.80; weight of quality=0.20)

BIM functions	Score	BIM functions	Score
3D Visualization	62%	Scheduling (4D Animation)	33%
Clash Detection	80%	Energy Analysis	52%
Facility Space Planning and Logistics	46%	Shop-drawing Process	50%
Code Validation	36%	Material Tracking, Delivery and mgt	25%
Constructability Analysis	67%	Stakeholder Engagement	70%
Structural Analysis	63%	Project Turnover & Closeout	44%
Cost Estimation & Quantity Take-off	51%	Facility Management	45%

6 CONCLUSION

The benefits provided by Building information modeling are frequently documented in literature (Becerik-Gerber and Rice, 2010; Meadati et al., 2011; Azhar, 2011; Bryde et al., 2013). However, small- to medium-sized firms fail to adopt and implement BIM as there is no common financial benchmark for making decisions regarding adoption of BIM functions. As an attempt to solve this problem, we conducted a survey to gather the tacit knowledge of BIM users. It was found that 72.5 % respondents believed that

BIM is not required for all the projects. As far as project delivery and procurement methods are concerned, Design-Build (DB) and 2-Stage RFP procurement method were ranked at top for facilitating successful BIM adoption. In addition, most BIM users (72.5%) believed that project size impacts the decision in using BIM and more than half (59.26%) of the respondents indicated that project objective impacts the decision of using BIM functions.

Using these findings, a decision making algorithm was developed that can aid new users in understanding the advantages and disadvantages of implementing BIM functions in a project. The project provides significant contribution to the body of knowledge; however, there are some limitations that need to be mentioned. First, to develop the algorithm we assumed that the decision to use or not to use BIM in a project depends on project delivery method and team selection. Future studies should be conducted to identify other influential variables on making decision to use BIM in a project. Second, we assumed that selecting different BIM functions can be determined mainly based on project size and objectives. However, other variables can also be critical in using BIM functions such as availability of skillful personnel in a company. Third, large number of respondents were from design-build firms; this can explain why structural analysis and energy analysis were adopted more than expectations among respondents. Finally, the developed algorithm needs to be validated by conducting real cases studies.

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