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Formulating Project-level Building Information Modeling Evaluation Framework from the Perspectives of Organizations: A Review

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Abstract: This study identifies Building Information Modeling (BIM) benefits in the presentations of previous project participants and specialties. Based on recent data, a framework for evaluating the project-level BIM benefits from the perspectives of different stakeholders involved in the project is proposed. In order to maximize the benefits for each user or stakeholder, the functions and methods for implementing BIM on construction projects are explained. The results show that the advantages of implementing BIM in construction projects can be effectively evaluated by the proposed framework. Results presented herein provide documentation to improve the understanding of BIM benefits to all construction industry stakeholders.

Key words: BIM; benefits; evaluation

1 Introduction

Building Information Modeling (BIM) has been widely used in the whole life cycle of infrastructure projects, including civil and mechanical engineering projects, to improve the efficiency and effectiveness of these projects[1]. The utilization of BIM has grown significantly in recent years and it has been used to support various specialties in different phases of construction projects. The full impact of BIM principles and methodologies on the evolution of design tools in the Architecture/Engineering/Construction (AEC) industry has recently become a research area topic. In the past ten years, BIM has drawn the attention of researchers. From a prior research review, BIM can improve visualization, communication and integration in construction projects[2]. As an emerging technology, BIM has played an important role in the built environment [3]. Previous research found that the implementation of BIM can certainly improve construction efficiency and decision making throughout the life cycle of a project [4, 5, 6]. However, there is hesitation in adopting these creative tools and processes [7]. The main

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reasons for this reluctance to incorporate advanced technology are uncertainty about the competitive advantages and lack of awareness regarding the technologies and related benefits [8]. Currently, there is no agreed basic methodology to evaluate the advantages of BIM. Instead, there are various opinions regarding the benefits of BIM, leading to some misunderstanding. Thus, a standard evaluation framework is needed to assess BIM implementation [9]. Such a framework can help multiple participants and specialists understand and evaluate BIM benefits.

Prior case studies have been done to evaluate the advantages of BIM implementations on actual construction projects. Khanzode et al. analyzed the quantitative and qualitative benefits of using BIM tools in Mechanical, Electrical and Plumbing (MEP) systems [3]. A survey was conducted to clarify the ambiguity surrounding BIM and to identify the mutual benefits of adopting BIM [10]. Succar et al. proposed a method to evaluate BIM projects from five perspectives, which are BIM capability stage, BIM maturity level, BIM competencies, organizational scale, and granularity levels [11]. However, it cannot be used for quantitative evaluation of BIM projects. bimSCORE was developed to evaluate the maturity of a BIM project [12]. However, it utilizes the same evaluation factors for different projects in spite of their different objectives. Considering the necessity and importance of applying BIM technology in the built environment, it can be inferred that an evaluation framework, which facilitates the implementation of BIM technology, would enlighten practitioners about the potential of BIM applications in construction project management. This would then deepen their understanding about the advantages of using BIM in their own projects.

To develop an applicable evaluation framework, it is necessary to understand and define the requirements of the industry users and how to analyze the actual benefits. Won et al. conducted case studies to validate the applicability of a success level assessment model for BIM project (SLAM BIM) [13]. Actually, according to the research conducted by Bakis et al. [14], case study analysis is the most appropriate method for investigating the benefits of information technologies. Case study analysis has been the most adopted method in previous research (will be explained in the following sections). However, the concerns of different participants are not quite the same, and these concerns change while the construction project moves forward.

Fortunately, much of the literature on actual implementation of BIM applications on construction sites is available in the form of papers and reports. Hence, this study collects and analyzes prior research to formulate and propose a project-level BIM benefits evaluation framework from the perspectives of different stakeholders involved in the project. The following section introduces the research approach. Section 3 analyzes the literature and extracts the various concerns of individual participants. In Section 4, an evaluation framework is formulated, and methods to calculate the benefits of BIM implementation are proposed. Specifically, in order to maximize the benefits for each type of user, the functions and methods of BIM implementation on actual construction projects are explained. The results can help construction industry practitioners better understand how to implement BIM technology to improve safety, reduce rework, reduce costs, and improve sustainability and effectiveness.

2 Research Approach

The effectiveness of BIM implementation in various situations, such as educational and industrial settings, has been evaluated[15]. Despite the topic of BIM having been studied by academics [16,17,18,19], and professional industry groups [20,21,22], the financial investment in this innovative methodological and technological solution makes private sector clients very prudent[23]. Research has shown that the major hurdle for adopting BIM into standard industry practice is to justify the additional cost to achieve the benefits discussed [24]. Therefore, the development of the ability to quantify the benefits of adopting BIM is required [23,25] .

In recent years, although there have been significant advances in BIM research and development, there is still a gap in providing a strong and reliable evaluation framework able to quantify BIM benefits. This paper is timely and aims to analyze and understand the existing BIM research map to:

- support the formulation of a BIM benefits evaluation framework;
- highlight the benefits for different stakeholders;
- understand the challenges of BIM implementation and suggest how they can be solved;
- forecast future research and development trends.

3 Review of BIM Benefits

3.1 Characteristics of Collected Articles

To make the framework applicable to various projects and stakeholders, we have analyzed a large number of case studies from existing literature. There were 65 relevant international journal articles were analyzed. The number of articles by year of publication is shown in Figure 1. The number of publications evaluating the benefits of BIM has grown considerably from 2006, with a substantial increase from 2011.

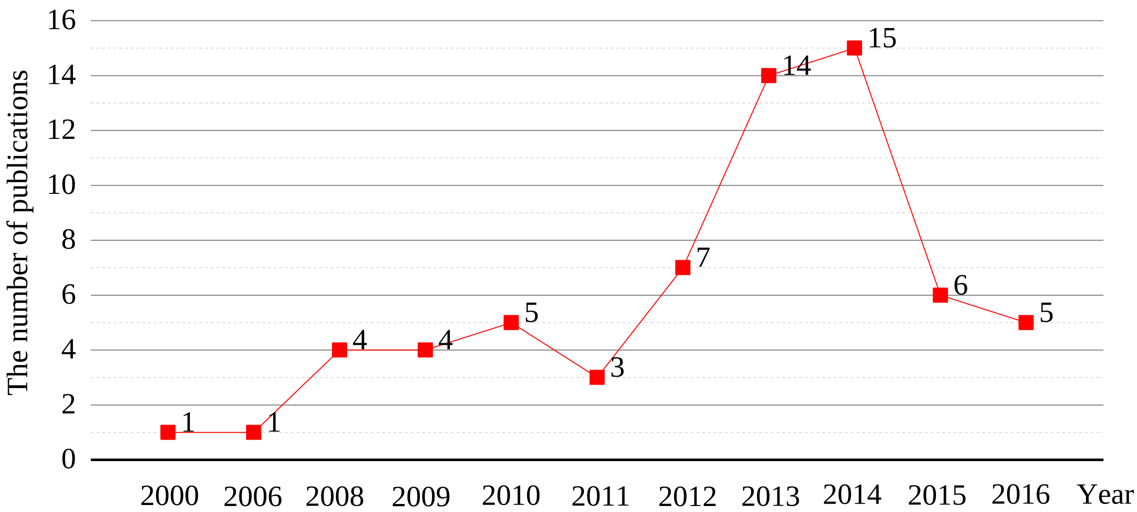

Fig. 1 Number per year of international journal publications related to BIM benefits evaluation research (journals listed in Table 1)

The list of publications analyzed includes (see Table 1) 29 research projects conducted in the United States between 2008 to 2016. The remaining research projects were conducted in different countries including the UK, Singapore, South Korea, Australia, Canada, Hong Kong, Germany, Israel, and Jordan. The analysis of these projects shows that since 2012 more countries/districts began to realize the importance of evaluating BIM benefits. Therefore, the formulation of an evaluation framework is both timely and necessary in order for the construction industry stakeholders to understand the importance of adopting BIM.

The analysis of the projects listed in Table 1 shows that the methods used for evaluating BIM benefits in individual projects are diverse and are classified into seven types [18,26]. These types listed in "Evaluation Methodologies" column of Table 1. In the "Project Participants" column, "all" means all the participants, specifically, including contractors, design agencies and owners. In the "phase" column, "all" means all the phases in construction management, specifically, including planning, design, construction and maintenance/operation phases.

Table.1 characteristics of existing BIM evaluation methods

NO	Year	Country /District	Evaluation Methodologies	Project Participants	Phase	Authors
1	2016	USA	Case study and model or process	Owners; Design agencies	Design	Wasmi et al. [27]
2	2016	Korea	Survey	Design agencies; Contractors	Construction	Lee et al. [28]
3	2016	Australia	Case study and model or process	Design agencies; Contractors	Design/Construction	Wang et al. [29]
4	2016	UK	Theory and general assumptions	All	All	Bradley et al. [30]
5	2016	Korea	Case studies	All	All	Won et al. [13]
6	2015	Hong Kong	Theory and general assumptions	All	All	Wong et al. [31]
7	2015	Singapore	Theory and general assumptions	All	All	Nath et al. [32]
8	2015	Hong Kong	Case study and model or process	All	All	Lu et al. [33]
9	2015	USA	Survey and Case studies	All	All	Francom et al. [34]
10	2015	China	Survey and Case studies	All	Design/Construction	Cao et al. [35]
11	2015	USA	Case study	All	Design/Construction	Terreno et al. [36]
12	2014	Poland	Theory and general assumptions	Design agencies	Design	Czmoch et al. [37]
13	2014	China	Model or process	All	All	Xu et al. [38]
14	2014	Iran	Survey and Case studies	All	All	Fazli et al. [39]
15	2014	Australia	Case study and model or process	Owners; Contractors	All	Nepal et al. [40]
16	2014	USA	Survey	Owners	All	Giel et al. [41]
17	2014	Pakistan	Survey	All	All	Masood et al. [42]

NO	Year	Country /District	Evaluation Methodologies	Project Participants	Phase	Authors
18	2014	Czech Republic	Theory and general assumptions	All	All	Tomek et al. [43]
19	2014	USA	Theory and general assumptions	All	All	Abdirad et al. [44]
20	2014	Australia	Theory and general assumptions	Owners	All	Love et al. [45]
21	2014	Germany	Survey and Case studies	All	All	Volk et al. [46]
22	2014	USA	Survey	Contractors	Construction	Boktor et al. [47]
23	2014	USA	Survey and case studies	All	All	Stowe et al. [48]
24	2014	USA	Survey and case studies	All	All	McGraw-Hill[49]
25	2014	USA	Survey and case studies	All	Design/Construction	Monteiro et al. [50]
26	2014	Australia	Theory and general assumptions	All	All	Wang et al. [51]
27	2013	Australia	Theory and general assumptions	Owner	All	Love et al. [23]
28	2013	USA	Case study and quantifiable findings	Contractors	Construction	Vaughan et al. [52]
29	2013	USA	Survey and case studies	Design agencies; Contractors	Design/Construction	Clevenger et al. [53]
30	2013	USA	Survey and case studies	Owners	All	Giel et al. [54]
31	2013	UK	Theory and general assumptions	Owners	All	Xu et al. [55]
32	2013	USA	Case study	Design agencies; Contractors	Design Construction	Luth et al. [6]
33	2013	USA	Survey	Design agencies; Contractors	Design/Construction	Bynum et al. [56]
34	2013	UK	Survey and case studies	All	All	Bryde et al. [57]
35	2013	Hong Kong	Case study and model or process	Contractors	Construction	Lu et al. [58]
36	2013	UK	Survey	All	All	Eadie et al. [59]
37	2013	USA	Theory and general assumptions	Design agencies; Contractors	Design/Construction	Solnosky et al. [19]
38	2013	Australia	Model or process	Design agencies	Design	Wang et al. [60]
39	2013	Italy	Case study	Design agencies	Design	Di et al. [61]
40	2013	Korea	Theory and general assumptions	Contractors	Construction	Park et al. [62]
41	2012	USA	Survey and case studies	All	All	McGraw-Hill[63]
42	2012	USA	Survey and case studies	All	All	McGraw-Hill[64]
43	2012	Canada	Survey and case studies	Owners	All	Neelamkavil et al. [65]
44	2012	Korea	Case study and quantifiable findings	Design agencies	Design	Lee et al. [66]
45	2012	Singapore	Case study and model or process	Design agencies	Design	Kandil et al. [67]
46	2012	UK	Case study and model or process	Design agencies	Design	Porwal et al. [68]
47	2012	Australia	Theory and general assumptions	All	All	Succar et al. [11]
48	2011	USA	Survey and case studies	All	All	Barlish et al. [18]
49	2011	USA	Survey and case studies	Contractors	All	Mehmet et al. [69]
50	2011	USA	Survey and Case studies	All	All	Azhar et al. [70]
51	2010	USA	Survey	All	All	Becerik-Gerber et al. [5]
52	2010	USA	Model or process	All	All	Ospina-Alvarado et al. [71]
53	2010	Australia	Theory and general assumptions	All	All	Succar et al. [72]
54	2010	USA	Survey and case studies	All	All	McGraw-Hill[21]

NO	Year	Country /District	Evaluation Methodologies	Project Participants	Phase	Authors
55	2010	Australia	Case study and model or process	All	All	Singh et al. [73]
56	2009	USA	Survey and case studies	All	All	Young et al. [7]
57	2009	USA	Survey	All	All	Zuppa et al. [10]
58	2009	USA	Survey	All	All	Patrick et al. [74]
59	2009	USA	Case study	Design agencies; Contractors	Design/Construction	Kuprenas et al. [75]
60	2008	USA	Case study and quantifiable findings	All	All	Khanzode et al. [3]
61	2008	USA	Survey and case studies	All	All	Azhar et al. [76]
62	2008	Israel	Case study and model or process	Design agencies	Design	Sacks et al. [77]
63	2008	Israel	Survey and case studies	Design agencies	Design	Kaner et al. [78]
64	2006	Jordan	Survey	Owner	All	El-Mashaleh et al. [79]
65	2000	UK	Theory and general assumptions	All	All	Andresen et al. [80]

From the review of the previous projects listed in Table1, the previous papers are categorized into evaluation of project-level BIM benefits, such as [57] and organizational level BIM benefits, such as [4]. As the most important part of the nature of BIM is project management related tools and processes, thus, a standard project-level evaluation framework is needed to assess BIM implementation. It has a potential use for multiple participants in improving collaboration between stakeholders, reducing the time needed for documentation of the project and, hence, producing beneficial project outcomes.

3.2 Classification of articles based on adopted research methods

Figure 2 illustrates the methods used based on the classification types given in [18] and [26]. “Case study and quantifiable findings” type utilizes case studies containing quantifiable measurements of BIM benefits. The “Case study” type analyzes BIM projects without quantifiable benefit measurements; e this type undertakes a qualitative approach. The “Case study and model or process” type utilizes a model or process to demonstrate how the benefits of BIM were obtained, but excludes quantifiable savings as a result of BIM utilization. The “Model or process” type proposes a framework or evaluation process, but is either (1) not used on an actual BIM project or (2) if claimed to be utilized on a project, this type does not present no any quantifiable results. The “Survey” type contains independent surveys including various questions targeting different stakeholders with different backgrounds. The survey aims to map those stakeholders’ opinions and perceptions of the benefits obtained from BIM adoption. The “Survey and case studies” type contains a survey targeting a specific project on which BIM has been adopted and, in some cases, interviews of the project team members are conducted. Publications focusing on “Theory and general assumptions” have addressed mainly theoretical frameworks and discussed potential benefits without any benchmarking in a real project.

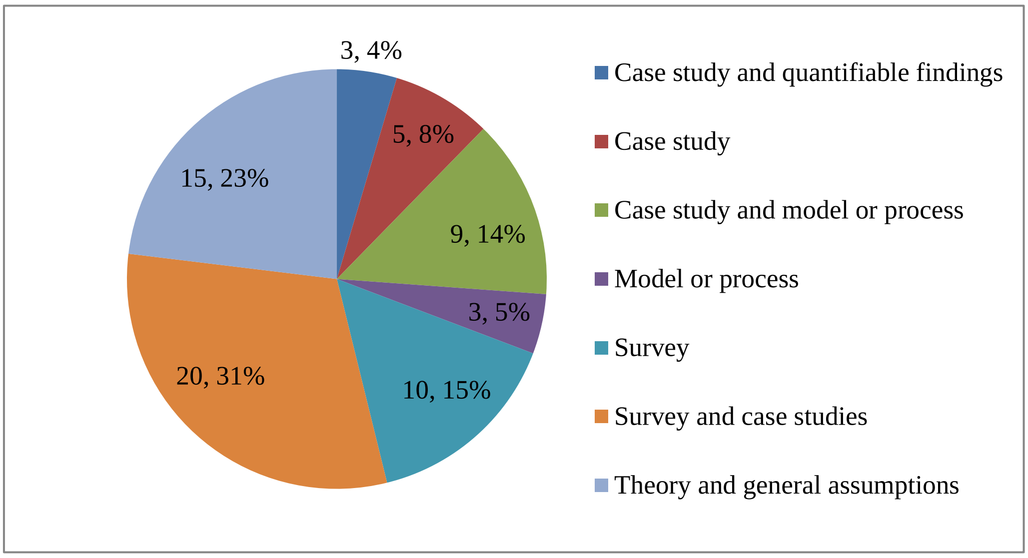

Fig.2 Literature Review-Summary of classifications

Figure 3 illustrates for each year between 2000 and 2016, the proportions of the methods used to evaluate BIM benefits. Over time, the BIM evaluation methods are more diverse and varied with a convergence toward surveys and case study analysis.

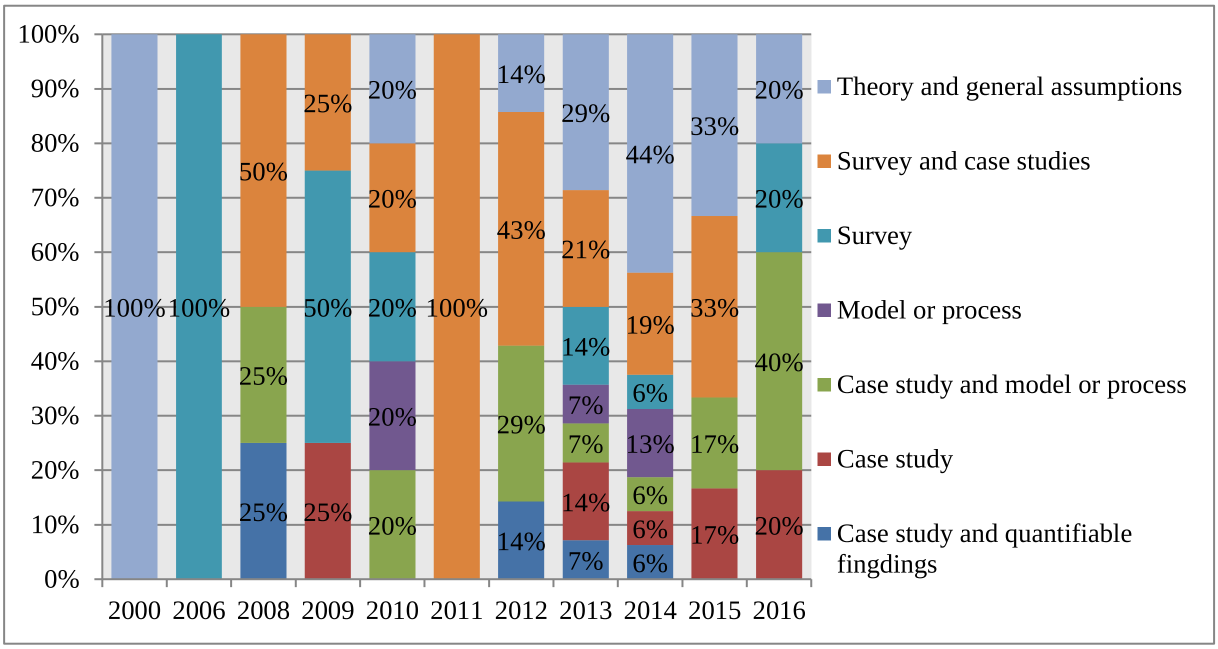

Fig.3 Percentages of the adopted BIM benefit estimation methods by publication year

3.3 Classification of articles by participants

Previous studies analyzed mainly the benefits of BIM considering the overall project lifecycle (Table 2) and all the participants listed in Table 1, see Figure 4. As indicated in Table 2, the main focus of the literature is on the design and the construction phases. However, the primary concern of individual participant varies and changes by phase. Thus, in the following sections, this paper attempts to fill the gap by analyzing BIM benefits from the perspectives of individual participants and address primary concerns by individual rather than by the whole organization.

Table. 2 Literature Review-Summary of Phase

Phase	Frequency
All phases	42
Planning	0
Design	18
Construction	14
Maintenance/Operation	0

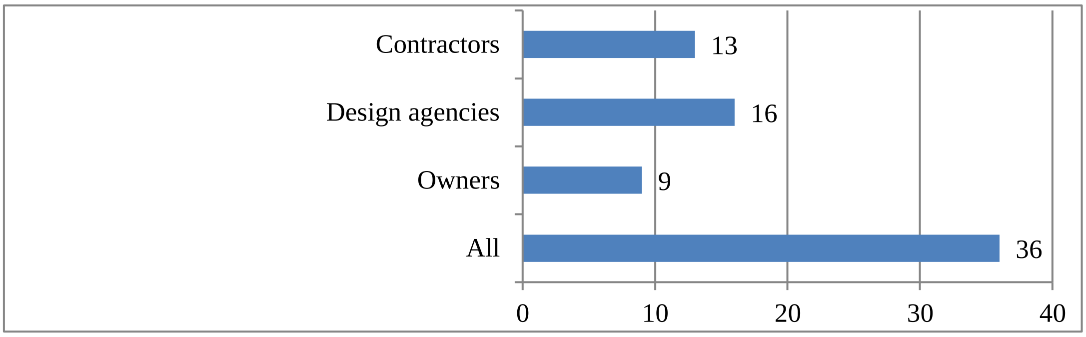

Fig. 4 Classification of articles by participants

Of course, different BIM users from the project participants are usually involved in different project phases involving different kind of benefits. For example, the designers give exclusive attention to the design phase. Owners are concerned with the whole project life cycle. Construction managers and contractors are naturally more interested in the construction phase. Detailed information about the relationships between the project participants and their concerned phase is illustrated in Figure 5.

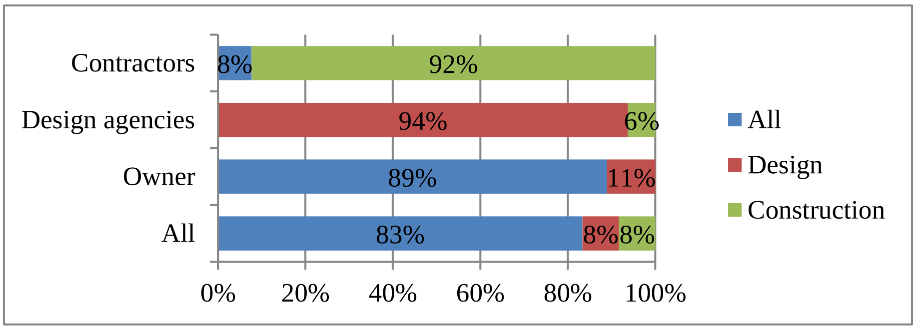

Fig. 5 Relationships between the project participants and their concerned phases

Another interesting finding in more recent research is the consideration of BIM benefits related to individual participants (see Figure 6).

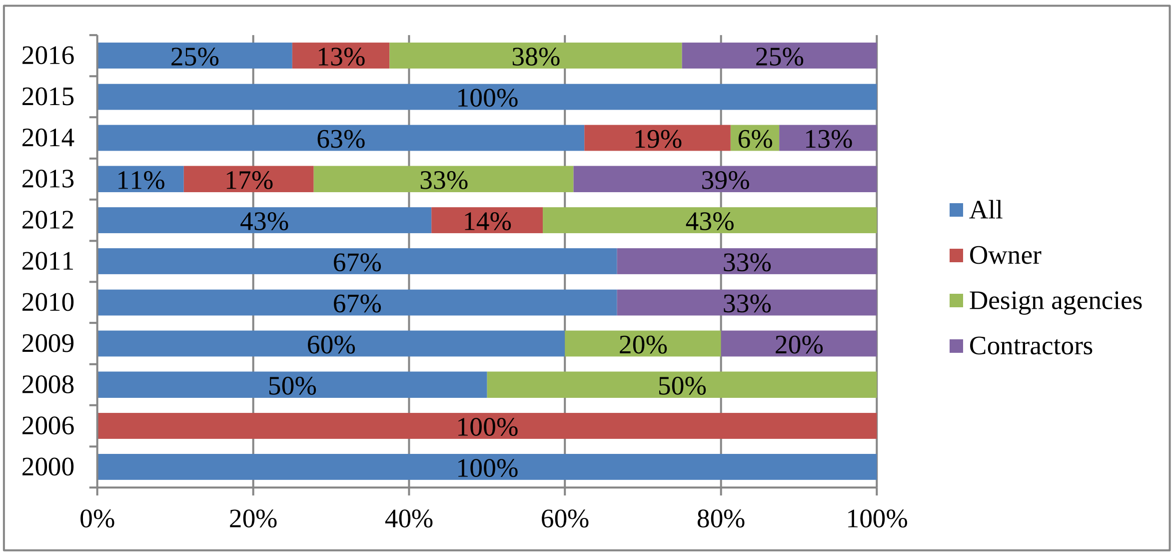

Fig. 6 Percentages of benefit analysis by participant by year of publication

3.4 Classification of articles by benefit indicators

The classification of articles by benefit indicators is illustrated in Table 3. In total, 23 benefit indicators were evaluated in the selected papers and reports, as shown in Figure 7. These benefits can then be categorized into four types, which are operational, strategic, organizational and managerial [23, 81], as shown in Table 4.

Table.3 Classification of articles by benefit indicators

NO	**Benefits**																						
	Operational												**Strategic**			**Organizational**			**Managerial**				
	Reduced cost	Quality improvement	Reduced project duration	Improved safety	Visualization	Sustainable	Productivity improvement	Reduced change orders	Fewer claims/litigation	Reduced errors and omissions	Reduced rework	Prefabrication	Competitive advantage	Market new business	Customer satisfaction	Coordination improvement	Staff's learning	Economization of labor	Communication improvement	Accurate data output	Model archiving	Negative risk reduction	Improved decision-making
1	√		√		√		√									√			√	√			√
2	√	√	√	√		√				√	√								√				
3	√				√		√			√	√	√											
4	√	√	√	√	√																		
5	√		√					√		√	√								√			√	
6						√																	
7							√												√				
8			√																√				
9		√						√															
10					√		√																

NO	**Benefits**																					
	Operational												**Strategic**			**Organizational**			**Managerial**				
	Reduced cost	Quality improvement	Reduced project duration	Improved safety	Visualization	Sustainable	Productivity improvement	Reduced change orders	Fewer claims/litigation	Reduced errors and omissions	Reduced rework	Prefabrication	Competitive advantage	Market new business	Customer satisfaction	Coordination improvement	Staff's learning	Economization of labor	Communication improvement	Accurate data output	Model archiving	Negative risk reduction	Improved decision-making
11							√			√						√			√	√			
12		√						√															
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18					√		√	√		√	√	√				√							
19	√					√		√		√							√		√			√	
20							√					√											√
21	√	√	√					√							√	√			√			√	
22	√	√	√	√				√								√						√	
23	√	√	√				√													√			
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41																	√						
42	√		√						√	√	√			√		√			√				
43	√	√	√	√	√	√	√	√	√	√	√	√		√					√				

NO	Benefits																						
	Operational												**Strategic**			**Organizational**			**Managerial**				
	Reduced cost	Quality improvement	Reduced project duration	Improved safety	Visualization	Sustainable	Productivity improvement	Reduced change orders	Fewer claims/litigation	Reduced errors and omissions	Reduced rework	Prefabrication	Competitive advantage	Market new business	Customer satisfaction	Coordination improvement	Staff's learning	Economization of labor	Communication improvement	Accurate data output	Model archiving	Negative risk reduction	Improved decision-making
44	√	√	√	√	√		√	√			√	√				√	√		√				
45	√	√	√					√		√	√								√				
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61					√								√			√			√				
62	√	√	√	√	√		√			√						√							
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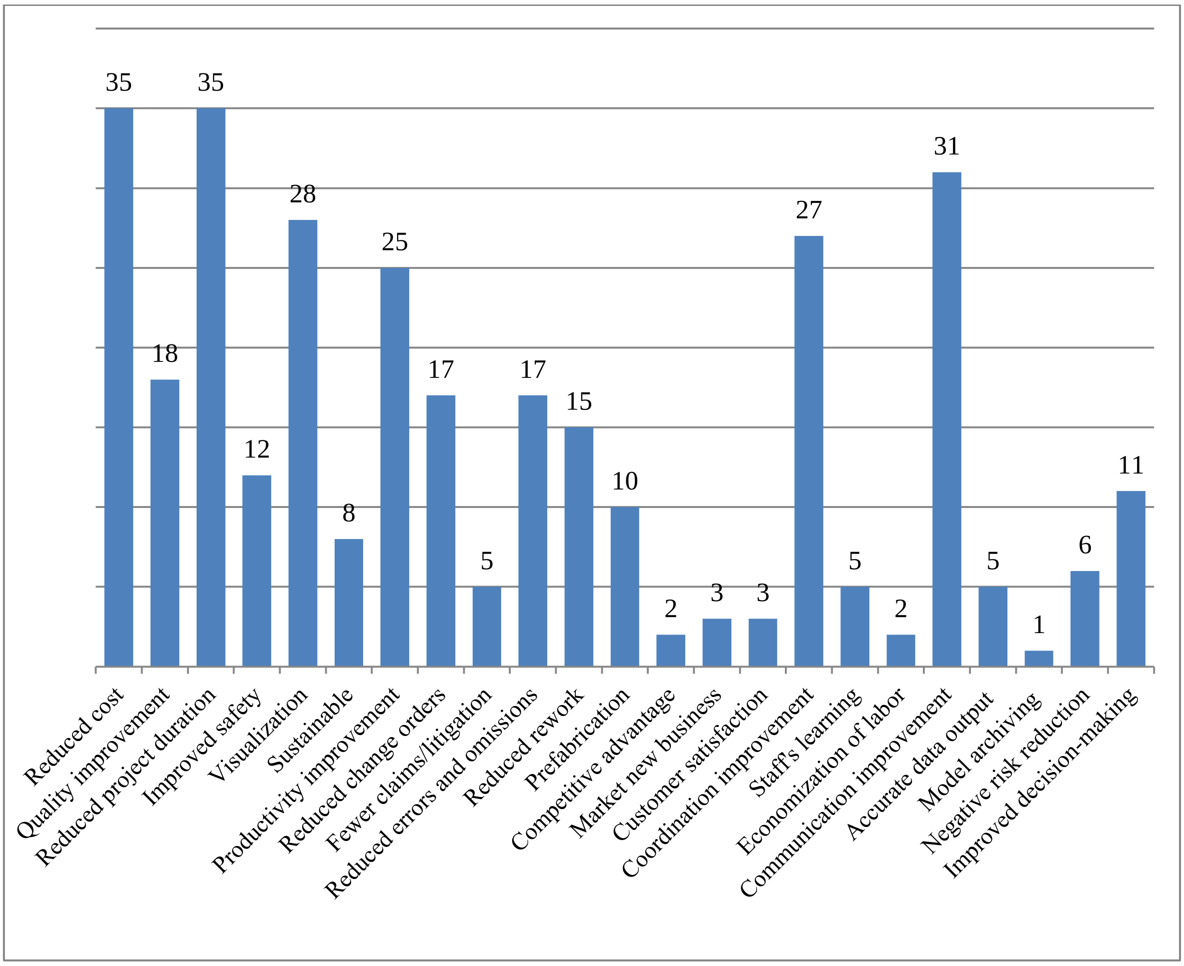

Fig.7 Numbers of articles by BIM benefit indicator

Cost and project scheduling being the primary concerns from the perspective of the construction industry; *reduced cost* and *reduced project duration* are the most discussed benefits. In addition, *visualization* and *communication improvement* are considered to be evaluating indicators of great importance. Table 4 shows that operational benefits were the most mentioned and they were important to both the industry and scholars.

Table. 4 Classification of BIM benefits

Classification	Percentage	Corresponding Benefits
Operational	70.09%	Reduced cost/ Quality improvement/ Reduced project duration/ Improved safety/ Visualization/ Sustainable/ Productivity improvement/ Reduced change orders/ Fewer claims (litigation) / Reduced errors and omissions/ Reduced rework/Prefabrication
Strategic	2.49%	Advantage in competition/ Market new business/ Customer satisfaction
Organizational	10.59%	Coordination improvement/ staff's learning/ Economization of labor
Managerial	16.82%	Communication improvement/ Accurate data output/ Model archiving/ Negative risk reduction/ Improved decision-making
Total	100%	

To date, the researchers have focused on reduced project duration and cost while putting little emphasis on sustainability, as indicated in Figure 8. Amongst the selected papers, only eight papers attempted to assess the benefit of BIM on sustainability. As BIM can contribute to achieve sustainable constructions [57, 82], it is surprising that there are not many practical studies about this issue. Thus, more future research might be needed to identify the benefits of BIM applications on sustainability.

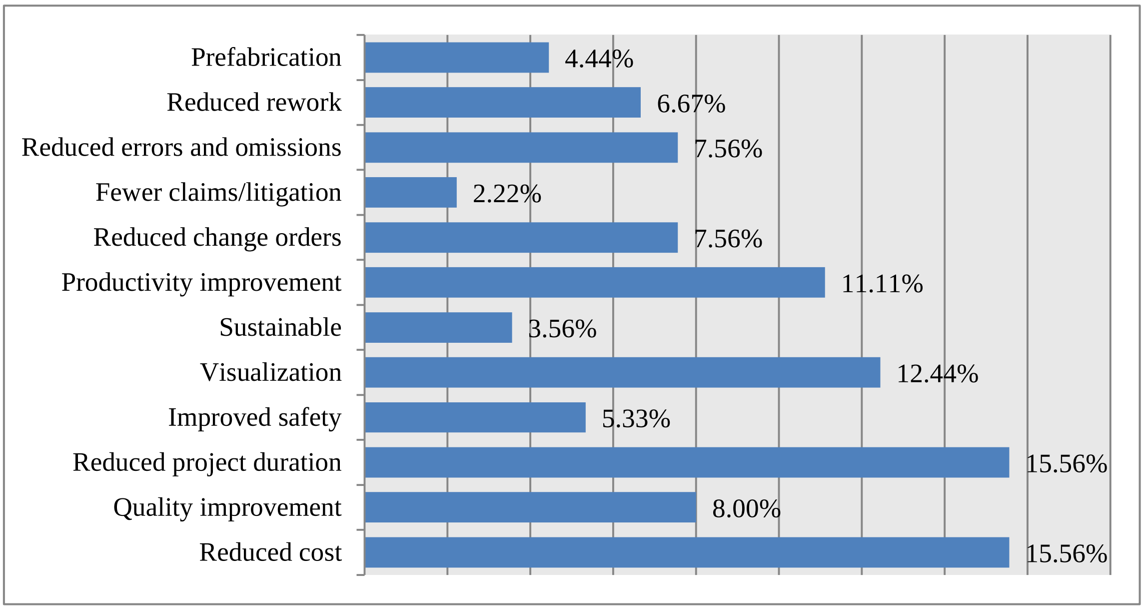

Fig.8 Frequencies of operational BIM application benefits

There might be a gap between what the industry and scholars find important when evaluating the BIM benefits. As illustrated in Figure 9, for strategic benefits, researchers have put more emphasis on customer satisfaction. From the point view of industry, marketing new business was proposed to be the primary benefit of implementing BIM technology [63]. Moreover, providing new service was nominated as a secondary benefit from the perspective of the industry; this has never been mentioned by any research publication. Thus, researchers should take into account the requirements of the industry in order to assess the benefits in a more practical way.

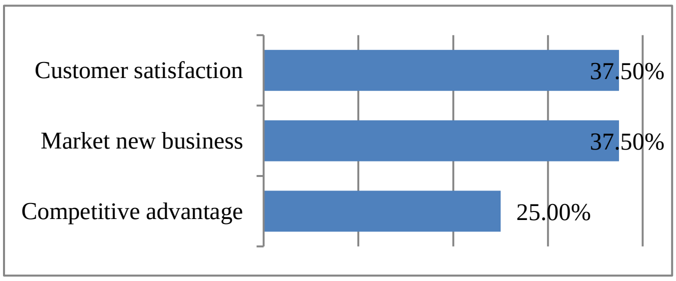

Fig. 9 Frequencies of strategic BIM benefits

According the information listed in Table 3, the organizational BIM benefits include economization of labor, staff's learning and coordination improvement. Figure 10 shows that the organizational BIM benefit was considered to be an effective tool to improve coordination. It shows that BIM adoption is more effective when it includes a continues professional development and training. Previous studies show that less research has been done in organizational benefits aspect compared to the other types of BIM benefits. It might be a future research direction.

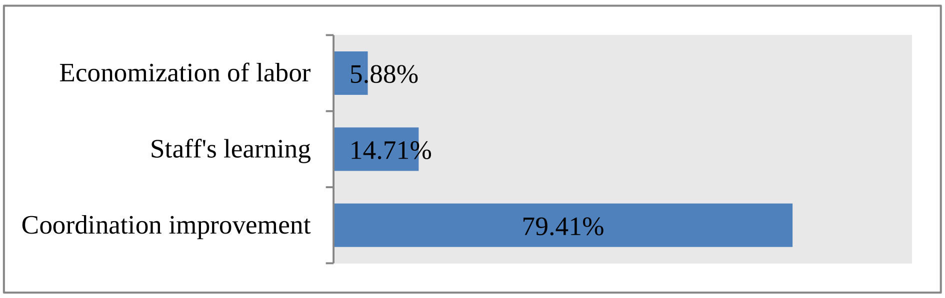

Fig. 10 Frequencies of organizational BIM benefits

In conclusion, the publication analysis shows a fragmented approach. When analyzing the previous studies of BIM benefits, operational benefits were a primary concern in all phases. Detailed information can be found in Figure 11. Managerial and organizational benefits did improve significantly thanks to BIM adoption during the construction phase compared to the planning, design and maintenance/operation phases. In conclusion, the research focus has often varied depending on the project phase. From the review we have undertaken, it appears that an individual project participant is more often concerned by individual or specific project phases. Operational benefits were of much concern in all phases of the construction projects. Figure 11 shows that researchers focused on analyzing the impact on the managerial and organizational aspects in the construction phase where in previous literature, BIM implementation was supposed to contribute more in the design phase.

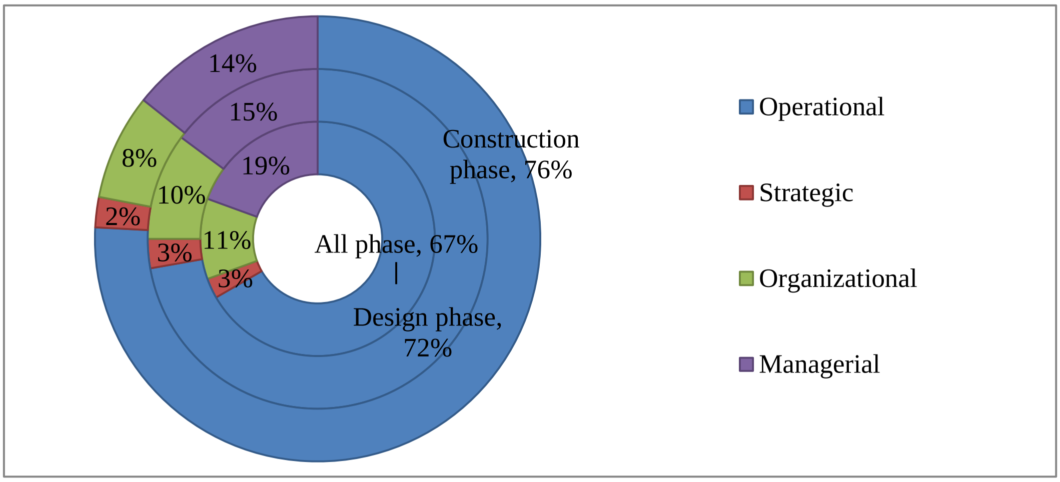

Fig. 11 Frequencies of individual BIM benefits from the perspective of construction phase

Figure 12 illustrates the relationships between the participants and their primary concerns, and shows that all participants focus essentially on the operational benefits. This can be explained by the cost and time driver of any construction project.

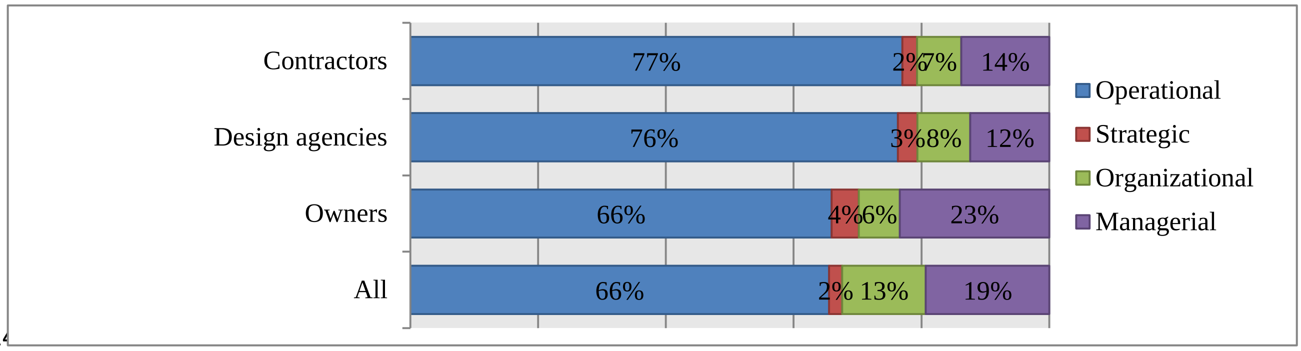

Fig. 12 The relationships between participants and their concerned benefits

4 Establishment of BIM benefits evaluation framework

Based on the literature review, a framework is proposed and illustrated in Figure 13. A BIM evaluation should include content, context and process [83]. Hence, understanding who affects the evaluation, what is being evaluated and how to evaluate benefits are fundamental to the evaluation framework. The proposed framework in this paper consists of three parts: 1) project participants, 2) benefits indicators and, 3) measurement methods. These are shown as the three axes in Figure 13. The relationship amongst these three axes will be explained in the following paragraphs and tables.

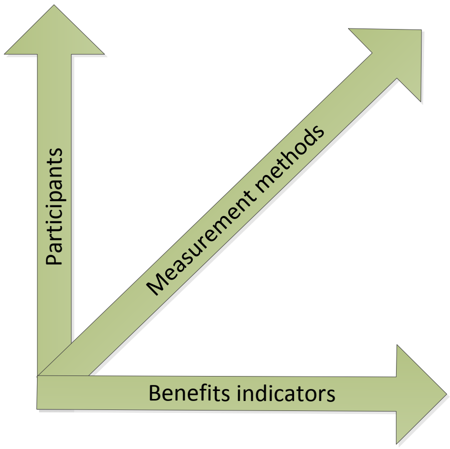

Fig. 13 BIM evaluation framework: participants, benefits indicators and measurement methods--tri-axial model

4.1 Relationship between measurement methods and benefits indicators axes

For different project participants, they have different expectations to implement BIM, thus have different benefit indicators. The BIM benefit indicators for different participants are identified according to the relevant literature. Depending on the nature of the indicator, quantitative or qualitative methods are used to measure the benefits [84]. Some of the indicators cannot be measured using quantitative means [23]. For the other indicators, the proposed framework provides measurement methods to calculate the cost/benefit ratio of BIM implementation. The chosen measurement method for each evaluating indicator is from the previous study which has been implemented in real construction projects. The methods adopted to measure the individual indicators are listed in Table 5. To evaluate the benefits of BIM; certain indicators such as satisfaction of owner, satisfaction of BIM user, etc. are of qualitative nature. Different methodology can be used to evaluate these indicators such as surveys and interviews.

Table. 5 measurement methods for different benefit indicators in the framework

Classification	Indicators	Measurement methods	Participants
Operational	Reduced cost [5,6,7,10,18,19,21,23,35,37,39,41,42,45-54,57,59-62,73-77,79,80]	Percent of the time projects are delivered on/under budget[70,85]	All
	Quality improvement[10,18,19,21,23,35,39,42,45,48,52,57,59,62,65,66,70,74,76,78,80]	Cost of Repairing Claims (Defects) / Total Project Cost[86]	All
	Reduced project duration[6,7,10,18,19,21,23,35,39,42,45-54,57,59-66,69-71,73-77,79,80]	Percent of the time projects are delivered on/ahead of schedule[70,85]	All
	Improved safety[3,21,45,46,48,49,23,19,18,7,10,74,79,60]	(the Quantity of Accidents)*100/ the total Number of Workers [86]	All
		(the Quantity of Work Days Lost)*100/ the Annual Average of Workers[86]	
Classification	**Indicators**	**Measurement methods**	**Participants**
Operational	Visualization[47-49,51,19,59-62,18,69-71,21,10,73-75,76,37,38,40,42]	Qualitative[70]	All
	Sustainable[46,48,49,56,59,67,68,70,5,7,21,61,35,37,41]	Energy consumption upgrade rate[87]	Design agencies; Operators
	Productivity improvement[47-49,51,52,23,6,58-62,19,18,70,21,10,74,76-80,35,36,40,44]	Qualitative[79,88]	All
	Reduced change orders [45,48,23,19,59,21,3,76,77,37,39-41]	Cost of change/total cost of project[56,89]	All
	Fewer claims/litigation[53,63,64,66,7,21]	Number of claim/litigation	Design agencies
	Reduced errors and omissions[47,49,19,61-64,66,5,21,10,35-37,40,41]	Costs of rework due to design errors[66,90]	Design agencies; Contractors
		Costs associated with schedule delays due to errors[66]	
	Reduced rework[47,49,51,52,19,60,62-64,66,18,21,7,75,3,80, 40,42]	Rework costs[90]	All
	Prefabrication[46,48,49,6,18,69,7,21,75,3,78,40,44]	Qualitative[7]	All
Strategic	Competitive advantage[23,65,21,76,79,80]	Qualitative[63]	All
	Market new business [49,63,7,21]	Qualitative [63]	Design agencies;
	Customer satisfaction[48,49,23,59-65,70,21,7,76,78-80,4-5,7,16,18-20,36,40-41,46,48-50,39]	Percent of repeat business customers[70,85]	Design agencies; Contractors
Organizational	Coordination improvement[45-52,57,19,59-61,65,18,69,70,71,72,75,3,1-6,8,14,16-17,20,34-36,38-39,44-45,73,35-40]	Qualitative[64]	All

	Staff's learning[23,38,41,58,21,72,80]	$L_{\mathrm{eff}}\mathrm{BIM(T)}=\int L_{\mathrm{eff}}\mathrm{BIM(T)} = \int\left[f_{(\mathrm{T})} - f'_{(\mathrm{T})}\right]$ Where $L_{\mathrm{eff}}\mathrm{BIM(T)}$ stands for aggregate learning effects contributed by BIM; and $f_{(\mathrm{T})}$ stands for best-fit learning curve for a repetitive task without BIM adoption; and $f'_{(\mathrm{T})}$ represents best-fit learning curve for a repetitive task using BIM[58]	Owners; Contractors; Operators
	Economization of labor[42,47,65,18,21,3,77,61]	Budgeted Cost of Man-hours / Actual Cost of Man-hours[86]	Owners; Contractors
		Planned Man-hours / Actual Man-hours[86]	
Classification	**Indicators**	**Measurement methods**	**Participants**
Managerial	Communication improvement [46-53,55,57,19,68,69,72,21,75,3,80,51,60,61,73,36,38,39,41]	Reduced number of requests for information (RFIs)[91,92]	Design agencies; Contractors
	Accurate data output[48,36,49,55,6,59,67,69,70,21,60,51]	Overestimate construction costs[85,89]	All
		Underestimate construction schedule [85,89]	
	Model archiving[6,69,62,73]	Qualitative [69]	Owners; Contractors; Operators
	Negative risk reduction[45,39,41,43,46,48,57,21,80,61]	Qualitative[21]	Design agencies
	Improved decision-making[23,6,60,72,44]	Qualitative [6,93]	Owners; Contractors

4.2 Relationship amongst measurement methods, benefits indicators and participants

Previous studies show that different project participants and BIM users have different primary concerns [94]. Based on the literature review, the BIM evaluation metrics of primary interest to the project stakeholders are also presented in Table 5.

From the review and based on the owner concerns, BIM implementation should include, but not be limited to: a) 3D modeling, clash detections and design coordination [95]; b) performance analysis such as energy and excavation simulation [96]; c) 4D modeling and scenario simulation [97]; d) quantity take-off [98] and cost analysis and; e) site training based on BIM[99].

In the case of design agencies concerns, BIM implementation should include, but not be limited to: a) 3D modeling[100], coordination between numerous drawings to identify potential conflicts or defect within the model[101]; b) design validation[102]; c) quantity take-off and cost analysis[103]; d) an effective communication environment based on BIM models[104,105]; and e) performance analysis, including energy[106] and evacuation simulation[107].

In the case of contractors, BIM implementation should include, but not be limited to: a) 3D modeling and clash detection[108]; b) design validation[109]; c) quantity take-off and cost analysis; d) 4D visualization and prefabrication[110], construction planning and monitoring[111,112] and; e) an effective communication web platform based on BIM models[113].

Using these functions, the indicators of different types BIM benefits can be improved. For instance, 3D modeling and design coordination can help to detect the design errors before construction, which may reduce the rework, change orders, project duration and construction cost. Furthermore, it improves the design coordination amongst different specialties and model archiving. Another example, 4D modeling and scenario simulation makes the owners and contractors understand the accurate difference between planned schedule and actual schedule. Together with the quantity take-off function, the difference between planned cost and actual cost can be calculated. Besides, the site workers can better understand the detailed working process before construction, thus it improves the working productivity.

5 Research Conclusions

BIM is becoming a well-established tool and an innovative methodology to improve the productivity in the entire life cycle of projects, which includes construction, operation and maintenance. Hitherto, some practitioners have hesitated to adopt this approach. The investment in BIM is justified on the basis of an evaluation of the benefits. The benefits of BIM implementation are divided into operational, managerial, organizational, and strategic factors. This paper presents a framework to analyze these benefits from the perspective of different participants and different phases. For each type of benefit, the method of measurement was suggested by analyzing prior research. To address the needs and interests of different users, the functions were identified and defined for future development of different BIM application systems in the most efficient way. The proposed framework prepared the ground for empirical research to evaluate the benefits of implementing BIM applications. This framework gives industry practitioners a better understanding of the effectiveness of BIM applications. Therefore, it will facilitate the adoption of BIM technology in the construction industry. While the proposed framework is inherently realistic, it is built based on a thorough literature review and of the authors' rich experience in developing, implementing and evaluating BIM systems. In future research, the authors will further validate the proposed framework while implementing BIM in new case studies supported by construction project owners within both the private and public sectors.

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