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Study on Quality Efficiency for Bim-Based Construction Projects

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Abstract
The Fourth Industrial Revolution (IR 4.0) has recently compelled the construction sector to employ Building Information Modelling (BIM) as a central repository for digital project information. BIM has thus become a major influence in the Architecture, Engineering, and Construction industries (AEC). Although BIM improves design quality by minimising disputes and decreasing rework, there is limited study on applying it throughout a project for quality control and effective information use. Thus, this paper explores and discusses the quality efficiency of BIM-based construction projects. There were 206 questionnaires distributed to government agencies/clients, consultants, and contractors. Quantitative data analysis was conducted using Statistical Package for Social Science (SPSS). Consequently, twenty-seven (27) attributes of quality efficiency of BIM-based construction projects were deemed the determining factor by the three research groups (Government, consultant, and contractor). The research result was to help BIM-based construction project players, especially government agencies/clients, contractors, and consultants, by giving a roadmap to be BIM-compliant and seeing the adoption process to attain BIM level 3 (full integration) for the Malaysian construction sector.
Keywords: AEC, Building Information Modeling, Construction, Efficiency, Quality

Introduction

Malaysia has begun implementing its Construction 4.0 Strategic Plan (2021-2025), which embraces the Fourth Industrial Revolution (IR 4.0) and outlines how the country's construction sector can navigate the rapidly changing business environment by utilising the digital revolution to its fullest extent (Construction Industry Development Board (CIDB) Malaysia, 2020). This Strategic Plan is the next step in the construction industry's transformation once the Construction Industry Transformation Programme (CITP) 2016-2020 is completed. 2020 Construction Industry Development Board (CIDB) reports that the CITP has centered its transformation initiatives on four core thrusts: quality, safety, professionalism, sustainability, productivity, internationalisation, and competitiveness. Digital technology, specifically BIM, is an integral part of the Quality, Safety, Sustainability, Productivity, and Competitiveness sub-strategies of the Construction 4.0 Strategic Plan. For building projects to meet quality, safety, sustainability, efficiency, and competitiveness standards, digital technology, specifically BIM, is crucial. Areas 8 (advance green growth for sustainability and resilience) and theme 3 (advance sustainability) of the Twelfth Malaysian Plan (RMK12) promote this notion. The RMK 12 additionally takes into account the policy enabler 2 (accelerating technology adoption and innovation) supported strategy.

According to Rohena (2011), BIM is radically altering the way construction project teams collaborate to maximise productivity and enhance the ultimate project results (cost, time, quality, safety, functionality, and maintainability) for all parties involved. Shourangiz et al (2011) discussed that BIM is a comprehensive idea of processes and tools that incorporate all data and information required for a project. BIM's process and tools occur during the project lifecycle; therefore, it must take into account the necessary data and information. In line with a definition from Construction Industry Development Board (CIDB) Malaysia (2016), BIM appears throughout the life-cycle of a construction project, modelling technology, and associated processes are used to create, share, analyse, and utilise digital information models. According to the preceding description, BIM can be defined as parametric modelling to support the project life cycle through the sharing of important data and information among stakeholders in order to improve the final project outcomes (cost, time, and quality).

Literature Review

BIM is expanding quickly in the construction sector, where it has significant positive effects on project execution in terms of quality, cost, and time. The absence of project pre-planning, uncertainty, or lack of clarity in the clients' integration of the project process, was causing misinterpretations and miscommunications of the project outcomes (Kestle, 2009). Therefore, improvements to the entire construction process are constantly needed, including higher-quality buildings, lower costs, shorter project durations, and more efficiency. Thus, in line with the government's effort through the CITP framework which highlighted productivity enhancement in the master plan, BIM has been identified as a key tool that has been playing a major role in improving the construction management background. BIM is a process of virtual design in the construction of a project. According to Chen and Luo (2014), although employing BIM throughout the project for construction quality control and effective information use has received minimal investigation, it is thought to improve design quality by removing conflicts and decreasing rework.

Table 1 presents the quality efficiency factors. In the development of BIM-based project, some project stakeholders failed to appreciate the potential of BIM. As such, to a certain extent it is inevitable for project client to enforce project teams to incorporate BIM in construction projects (Henttinen, 2010). Initially, clients' governance is across project phases from strategy formulation until completion. This means to say that client governance in the project to be constructed are within budget and frequent cost information, value-adding activities, stipulated time frame, and high standard quality products ((CIC) The Computer Integrated Construction Research Group, 2010). According to Porwal & Hewage (2013), clients can drive significant improvement in the cost, value, and carbon performance through the use of BIM as an open and shareable asset information model. One of the most important steps in the planning process is to clearly define the potential value of BIM among project team members through defining the overall demand for BIM implementation. These demands could be based on project performance and include items such as reducing the schedule duration, achieving higher field productivity, increasing quality, reducing the cost of change orders, or obtaining important operational data for the facility (CIC, 2010; Jadhav, 2011; McGraw-Hill Construction, 2014).

Table 1
Quality Efficiency Factors

Quality Efficiency	Authors
1) Working relationship	(Henttinen, 2010)
2) Improved contract documentation	(McGraw-Hill Construction, 2014a)
3) Free from defects on completion	(Jadhav, 2011; Latham, 1994)
4) Building facilities to reflect the future needs	(CIC, 2010)
5) A structure that looks and functions as intended	(Ahmad, 2008; Jadhav, 2011; Olsen and Taylor, 2017)
6) Design to be flexible	(CIC, 2010; Latham, 1994; Olsen and Taylor, 2017)
7) Supported by the worthwhile guarantees	(Latham, 1994; McGraw-Hill Construction, 2014a; Rezaian, 2011)
8) Functionality	(Ahmad, 2008; Henttinen, 2010; Olsen and Taylor, 2017)
9) Pleasing appearance to look at	(Ahmad, 2008; Latham, 1994; Porwal and Hewage, 2013)
10) Management competency	(Jadhav, 2011; Porwal and Hewage, 2013)
11) Safety	(Ahmad, 2008; Henttinen, 2010)
12) Better quality building product	(Ahmad, 2008; CIC, 2010)
13) Fit for the purpose	(Latham, 1994)
14) Reliability	(Ahmad, 2008; Henttinen, 2010)
15) Increase productivity	(Ahmad, 2008; Porwal and Hewage, 2013)
16) Improved decision-making	(Henttinen, 2010; McGraw-Hill Construction, 2014a; Rezaian, 2011)
17) System coordination for quality checking	(Rezaian, 2011)
18) Rigorous professional service	(CIC, 2010)
19) The project provides surprises	(Henttinen, 2010)
20) Achieving pre-defined standards	(Ahmad, 2008; Jadhav, 2011; Rajendran, Seow, and Goh, 2014)
21) Construction competency	(Porwal and Hewage, 2013; Rezaian, 2011)
22) Evaluate daylighting	(Henttinen, 2010; Rezaian, 2011)
23) Aesthetic value	(Henttinen, 2010)
24) Good facility performance	(Ahmad, 2008; Henttinen, 2010; McGraw-Hill Construction, 2014a; Rezaian, 2011)
25) Design services	(Porwal and Hewage, 2013)
26) Environmental performance is more predictable	(Rezaian, 2011)
27) Early occupation	(Henttinen, 2010; Rajendran et al., 2014)

Quality is an ambiguous term to understand differently by different people. It is sometimes defined as activities designed to improve organisation services known as pre-defined standards (Rezaian, 2011). Improving quality is to enhance the customer (end-user) satisfaction, function as intended, comfort, and increase productivity. It is also believed that refers to the proper quality management mostly in the design and construction phases. It recognised three categories of quality: functionality, comfort, and impact (Ahmad, 2008). Quality on functionality refers to the arrangement, quantity, and inter-relationship of spaces and how the building is designed to fulfill client needs. In addition, quality of comfort refers to how well the building is constructed, its structure, engineering system, safety quality, the coordination of the building, and its performance. Meanwhile, quality on impact refers to the ability of the building to delight, uplift the local community and environment, intrigues, and design contribution of architecture. For the good quality of BIM-based construction projects, they must contain a tremendous amount of information and be relied upon by the parties as the primary source of information. Depending upon how BIM is utilised on a project, enough information on contract documents is necessitated (Olsen and Taylor, 2017). Therefore, this paper explores and discusses the quality efficiency of BIM-based construction projects.

Research Methodology

A questionnaire survey was chosen as an appropriate mechanism. Therefore, a wide survey targeting AEC professionals in the Malaysian construction industry was conducted, to answer the stated questions in greater detail. The survey design was based on methods discussed by (Fink, 2006). The researchers have decided to choose AEC professionals practitioners in Malaysia according to the three following criteria: sufficient practical experience of BIM; adequate knowledge of data management; and willingness to participate. As shown in Table 2, out of 381 respondents, 206 questionnaires were completed and returned within six months duration representing 54.07 percent. The response rate of 54.07 percent is appropriate in construction management research since the previous research response rate in the construction industry questionnaire survey is around 20 to 30 percent (Akintoye, 2010; Black et al., 2000) received a response rate of 26.7 percent, while (Li et al., 2005) received 12 percent and (Takim, 2005) receive 20.9 percent. The main contributors to the survey were construction practitioners and key players in BIM that including AEC professionals, BIM Managers, BIM researchers, IT technicians, contractors, and clients. The research involved representatives from a variety of organisations across the architectural design, engineering, and ICT disciplines. Hence, the total response rate of 54.07% is considered overwhelming for this research.

Table 2
Summary of Response Data

No	Type of organisations/respondents	Number of questionnaires		Percentage return (%)
		Sent	Return	
1	Government agencies/clients	106	67	32.52
2	Consultants	125	60	29.13
3	Contractors	150	79	38.35
	Total	381	206	100.0

The questionnaire was analysed using SPPS version 24 software. The purpose is to conduct relevant statistical analysis such as examining and screening the data in terms of coding, outliers, and normality as well as to gain an overview of the data by computing the frequency means and Analysis of Variance (ANOVA) and Measure differences in the distribution of two related variables (Independent T-Test (Sig. p)).

Analysis and Discussion

Results from the questionnaire survey revealed the quality efficiency of BIM-based construction projects. Three groups of respondents are involved in the data collection (i.e., Government, consultants, and contractors). In this study, the level of criticality is based on the criticality formula developed by Li (2003); Takim (2005), in which the overall mean score is divided into five (5) levels of criticality. The value of cut-off demarcation is calculated using a formula MS=((s)-1)/f (Li, 2003). The ‘s’ value is implied as the maximum score given to each factor measure and ‘f’ is the scale to categorise the mean score. As for this research using a 5 Likert-scale which represents ‘s’ value, and ‘f’ represent 5 levels of criticality, the level of criticality is denoted as *4.2-5=extremely critical, 3.4–4.1=very critical, 2.6–3.3=critical, 1.8–2.5=somewhat critical, and 0–1.7=not critical.*

Table 3
Quality Efficiency in BIM-Based Construction Projects

Criticality	Quality Efficiency	Overall Mean	R	Gov. (N=67)	R	Cons. (N=60)	R	Cont. (N=79)	R	Independent T-Test (Sig. p)
Ext. Critical	Working relationship	4.32	1	4.37	1	4.35	5	4.25	1	0.435
Ext. Critical	Improved contract documentation	4.31	2	4.31	2	4.48	1	4.16	2	0.257
Ext. Critical	Free from defects on completion	4.25	3	4.25	3	4.42	2	4.13	3	0.344
Ext. Critical	Building facilities to reflect the future needs	4.21	4	4.21	5	4.40	3	4.08	4	0.943
Very Critical	A structure that looks and functions as intended	4.15	5	4.22	4	4.27	8	4.00	5	*0.050**
Very Critical	Design to be flexible	4.13	6	4.12	8	4.38	4	3.95	7	0.915
Very Critical	Supported by the worthwhile guarantees	4.12	7	4.13	6	4.32	7	3.95	6	0.128
Very Critical	Functionality	4.06	8	4.13	7	4.25	9	3.85	10	0.879
Very Critical	Pleasing appearance to look at	4.01	9	4.03	11	4.17	13	3.89	8	0.179
Very Critical	Management competency	4.00	10	4.06	10	4.08	20	3.87	9	0.282
Very Critical	Safety	3.99	11	4.10	9	4.03	22	3.85	11	0.901
Very Critical	Better quality building product	3.96	12	3.96	18	4.13	17	3.84	12	0.164
Very Critical	Fit for the purpose	3.96	13	3.91	22	4.33	6	3.72	16	0.951
Very Critical	Reliability	3.95	14	3.99	14	4.15	14	3.76	14	0.278

Very Critical	Increase productivity	3.94	15	4.00	13	4.12	19	3.75	15	0.113
Very Critical	Improved decision-making	3.94	16	3.97	17	4.22	11	3.71	17	0.132
Very Critical	System coordination for quality checking	3.93	17	3.94	20	4.15	16	3.76	13	0.224
Very Critical	Rigorous professional service	3.93	18	3.96	19	4.23	10	3.68	20	0.382
Very Critical	The project provides surprises	3.93	19	4.01	12	4.15	15	3.68	19	0.641
Very Critical	Achieving pre-defined standards	3.90	20	3.97	16	4.12	18	3.68	20	0.119
Very Critical	Construction competency	3.85	21	3.97	15	3.93	24	3.68	18	0.350
Very Critical	Evaluate daylighting	3.84	22	3.93	21	4.05	21	3.62	24	0.512
Very Critical	Aesthetic value	3.83	23	3.87	23	4.20	12	3.53	25	0.707
Very Critical	Good facility performance	3.80	24	3.87	24	3.90	23	3.66	22	0.734
Very Critical	Design services	3.73	25	3.70	27	3.88	26	3.65	23	0.150
Very Critical	Environmental performance is more predictable	3.71	26	3.84	25	3.88	25	3.48	26	0.673
Very Critical	Early occupation	3.61	27	3.73	26	3.75	27	3.39	27	0.384

*The mean difference is significant at the 0.05 level
* Level of criticality: 4.2 - 5 = extremely critical, 3.4 – 4.1 = very critical, 2.6 – 3.3 = critical, 1.8 – 2.5 =somewhat critical, and 0 – 1.7 = not critical.

Therefore, out of twenty-seven (27) factors listed, four (4) factors were perceived to be 'extremely critical. These are *working relationships* (overall mean value =4.32), *improved contract documentation* (overall mean value=4.31), *free from defects on completion* (overall mean value=4.25) and *building facilities to reflect future needs* (overall mean value =4.21). The remaining twenty-three (23) factors are regarded as 'very critical' ranging from the structure *that looks and functions as intended* (overall mean value=4.15) to the *early occupation* (overall mean value=3.61). Once again, comparisons between government, consultants, and contractors were executed. Undoubtedly, government and contractors ranked almost similar factors on *quality* as 'extremely' and 'very critical' consecutively. Both ranked *working relationship* 1st (mean values of 4.37 and 4.25), *improved contract documentation* ranked 2nd (mean values of 4.48 and 4.16,) and ranked 3rd *free from defects on completion* (mean values=4.25 and 4.13).

Meanwhile, once again, consultants ranked differently by ranking *improves contract documentation*, free *from defects*, and *building facilities to reflect future needs* as 1st, 2nd, and 3rd. This implies that factors in *working relationships* are the most critical factor which relates to quality in BIM-based construction projects for both Government and contractors as they are the largest beneficiaries of BIM technology apart from the completeness of the BIM documentation. Whilst consultants are concentrating purely on the completeness of documentation. As mentioned in the literature, the good quality of BIM-based construction projects must contain a tremendous amount of completeness information for BIM documentation (Olsen and Taylor, 2010). In addition, consultants selected *building facilities to reflect future needs* 3rd (mean value=4.40) and *design to be flexible* 4th (mean value=4.38). The reasons could be due to many processes in FM and deconstruction are not aligned with BIM, hence, there are no specific contracts developed and standardised for integrated practices to date. Therefore, the design needs to be flexible to reflect future needs (Epstein, 2012).

The results of an independent t-test One-Way ANOVA (Table 2) indicated that one (1) out of twenty-seven (27) *quality* factors are statistically significant difference of opinion between Government, consultant, and contractor namely *structure that looks and function as intended*. This implies that the null hypothesis on this factor cannot be accepted ($p<0.05$). Based on group differences tests using two independent samples, (Table 3), it is noted that the contractor respondents contributed to the difference between the groups (Government/contractor=0.050, consultant/contractor, p=0.009). The results suggested that the *structure that looks and functions as intended* is of lower priority (mean value=4.00) to contractor groups. The test revealed that contractors' opinions contributed to the differences. In a normal situation, the duties of the contractors are to execute the project according to the drawing, following specifications, and deliver the product based on cost, time, and quality. By right, being a contractor, he must deliver the structure that looks, and functions as intended. In contrast, contractors ranked this factor as a lower priority which is not always the case. Therefore, the probable reason for this predicament could be due to misinterpretation while completing the questionnaire survey.

Table 3
Group Differences Test using Test of Two Independent Samples for Quality Efficiency

	Quality Efficiency	Government/ Consultant (Sig. *p*)	Government/ Contractors (Sig. *p*)	Consultant/ Contractors (Sig. *p*)
Quality	A structure that looks and functions as intended	0.424	*0.050**	*0.009**

*The mean difference is significant at the 0.05 level

Conclusion

In conclusion, twenty-seven (27) attributes of quality efficiency of BIM-based construction projects were deemed the determining factor by the three research groups (Government, consultant, and contractor). The research result was to help BIM-based construction project players, especially government agencies/clients, contractors, and consultants, by giving a roadmap to be BIM-compliant and seeing the adoption process to attain BIM level 3 (full integration) for the Malaysian construction sector. Besides, these insights can be used as the basis for the project practitioners to review and revise their existing BIM implementation in construction aspects in Malaysia. The perception that the BIM implementation approach increases project cost should be corrected by expanding the focus to the wider dimension of improving project quality and value for money in the long run, thus, leading to client satisfaction. As the Construction 4.0 Strategic Plan aims to increase productivity through rolling out technology (BIM) advantages across the project life-cycle through regulations, reference centres, competency, and learning for BIM adoption, thus BIM-based construction project implementation is a potentially practical approach to improve the industry. Moreover, this study helps construction practitioners to achieve IR 4.0 and recognise BIM implementation as one of the enablers to improve the BIM particularly BIM responsible and resilient, at the same time contributing to the economy and indirectly help to ensure the overall wellbeing of a nation.

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