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ASSESSING COST AND BENEFIT ATTRIBUTES OF BUILDING INFORMATION MODELLING (BIM) IMPLEMENTATION IN MALAYSIAN PUBLIC AGENCY: PLS-SEM APPROACH

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***SUMMARY**: One of the main constraints posed during the implementation of Building Information Modelling (BIM) is the high cost of adoption. This leads to studies related to value management in project and organizational contexts, especially for the public sector. However, the empirical measurement of BIM value must be done systematically to produce more accurate and valid results for applications. Therefore, this study attempts to pave the way for development of Cost Benefit Analysis (CBA) of BIM implementation in Malaysian Public Works Department (PWD) by determining the BIM benefit attributes that have been realized and cost attributes that are needed for that. A total of 150 survey questionnaires were distributed to four design departments in Malaysian PWD Headquarter (HQ) to be rated using 5-points Likert's interval scale. Based on the data collected, the results were analyzed using Confirmatory Composite Analysis (CCA) as a method of confirming measurement quality (MCMQ) in Partial Least Square Structural Equation Modelling (PLS-SEM). The study model was conceptualized as a reflective-formative type II Hierarchical Component Model (HCM). The results indicate key benefit attributes and cost attributes related to two main BIM uses in Malaysian PWD current practices which are the 'design review' and 'automated clash detection'. Based on the final form of the model, there was a total of eight key benefits of BIM implementation which are 'lower cost', 'better scenario and alternative analysis', 'improved communication', 'improved coordination', 'improved output quality', 'better change management', 'less rework', and 'fewer error'. On the other hand, three cost attributes that were confirmed are 'software related investment', 'hardware related investment' and 'infrastructure cost'. This paper provides researchers on the approach of confirming key items needed to measure BIM value and is hoped to assist the value analyst to perform the Value Management (VM) analyses for their projects.*

***KEYWORDS**: Building Information Modelling (BIM), benefit, return, Partial Least Square Structural Equation Modelling (PLS-SEM), Hierarchical Component Model (HCM).*

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1. INTRODUCTION

The public sector plays a vital role in leading the industry towards BIM adoption. In recent years, BIM implementations continue to increase intensively as more government bodies and non-profit organizations of various countries worldwide implemented BIM in their projects and provided different BIM standards and solutions (Cheng et al., 2015). In Malaysia, BIM was introduced since 2007 to overcome various inefficiencies of the conventional method in construction industry such as the fragmentations among its players and failure to complete the projects within stipulated time and cost (Brahim, 2018).

Upon assessing BIM adoption in the public sector, various challenges have prompted studies on BIM value and benefit measurement. These studies are essential not only in academic contexts but also for industry practitioners. A review study conducted by Sriyolja et al. (2021) on papers published between the year 2013 to 2019 revealed that the cost of BIM was the main constraint that hinders BIM implementation. Furthermore, the benefits of BIM were considered lower than the implementation cost leading to the assumption that BIM adds cost (Sriyolja et al., 2021). This is also supported by survey data from the Malaysia BIM Report 2019 which shows a decrease in percentage of respondents who believe that BIM provides value (CIDB, 2020). This has so far coerced the researchers and value analysts to develop an applied method to measure and validate BIM benefits in their practice.

There are many tools and techniques to measure BIM value. This includes Return on Investment (ROI) (Autodesk, 2004; Giel & Issa, 2013; Ham et al., 2018; Stowe et al., 2014; Walasek & Barszcz, 2017) and Cost-Benefit Analysis (CBA) (European Commission, 2021; Lu et al., 2014; Oesterreich & Teuteberg, 2018). However, the BIM values reported across the studies are not consistent. According to Sompolgrunk et al. (2021), the ROI for BIM implementation ranges greatly from -83.3 percent to 39,900 percent due to differences in returning factors and variables. The lack of industry standards to benchmark BIM ROI of different BIM projects in a more structured approach has been considered a gap and limitation for analyst in estimating the true value of BIM investment. Hence, measurement of BIM benefits must be done systematically by following certain set of controlled variables that could immensely influence the final valuation of BIM benefits.

Therefore, the purpose of this study is two-fold. Firstly, the study determine BIM benefit attributes according to predetermined variables. Subsequently, this study aims to discover BIM cost attributes that are needed for the realization of BIM benefits. The rest of this paper is organized as follows. BIM cost and benefit attributes were compiled from extensive literature review as the theoretical foundation. Next, the Confirmatory Composite Analysis (CCA) as a method of confirming measurement quality (MCMQ) in Partial Least Square Structural Equation Modelling (PLS-SEM) is adopted to analyse BIM cost and benefit attributes in Malaysian PWD. This synthesis of existing research enriches the methodology and analytical approach, ensuring that the study's findings are grounded in a robust theoretical framework. Finally, the results were validated and discussed. This study contributes to understanding that different BIM benefit attributes could be realized from different BIM uses and BIM cost as an investment in the BIM adoption process. By systematically analysing predetermined variables, the study unveils a set of factors that are integral to realizing the advantages associated with BIM implementation. This endeavour enriches the existing body of knowledge by providing a structured framework for comprehending the diverse benefits that BIM brings to the construction domain. The results of this study could be used as a precursor for the BIM benefit measurement process in the government agency.

2. BACKGROUND INFORMATION

2.1 Factors Influencing the Value of BIM Benefit

Previous studies have uncovered a more structured approach to measure BIM benefits. This includes the development of Impact Cube by Davidson (2003) and Benefit Identification Model by Persaud (2007) to identify the types of benefits to calculated. This concept reveals different dimensions by which costs and benefits of any intervention could be classified. In the context of BIM implementation, different benefits could be categorized based on to whom the benefits or costs will be incurred based on the 'stakeholder' dimension. According to the study done by Ham et al. (2018), the cost of design errors that are carried forward from design phase to the construction phase will be incurred by the contractors. This situation has shown that different party in the project will have to produce the effort for the other party to reap the benefits and Walasek & Barszcz (2017) confirm that most of the benefits of BIM implementation are derived by the project owner and contractors while the designers are expected to invest in a great degree in the BIM adoption.

Another theory that are closely related to BIM benefit measurement is the Benefit Realisation Management (BRM) theory. BRM is a process which is performed to ensure the expected benefits such as BIM values to be realized (Love et al., 2014). The benefit realisation approach emerged in the early 1990's in the information system and technology (IS/IT) sector to help manage the delivery of expected business benefits as opposed to the traditional performance-based criteria of time, cost, and quality metric usage. The benefit relationship with various forms of determinants such as activity, enablers, resources are crucial to ensure a holistic and accurate measurement. This resonates with the awareness of which benefits, or value are related to different BIM process, or workstreams, or uses (Chahrour et al., 2021; European Commission, 2021).

Mohamed et al. (2023) has gathered different factors that could determine the benefit of BIM namely the 'project context', 'stakeholder', 'time', and 'type' dimension. It is adapted from the Benefit Identification Model by Persaud (2007) and Davidson (2003). Several modifications were made to the model to suit the needs of BIM benefits measurement by considering the approach of BRM literatures.

Although the cost of BIM adoption does not appear to be directly related to the realization of net BIM benefit, several factors that influences BIM benefits can be linked towards the expenditures needed to be spent on. A higher organizational BIM capability will have higher BIM competency in the staff which hypothetically will increase the cost incurred to the organisation such as training cost or increased in labour cost for BIM-competent staff as compared to those who can only work in traditional CAD software and work process. Another point of view is the increase in expenditures following more advanced BIM uses or activities that might need higher investment value on software or hardware. Hence, it is also important to assess the BIM cost attributes based on the benefits that have been realized.

2.2 BIM Cost Attributes

Investment of BIM in project context will occur at different points along BIM adoption timeline and the measurement of investment is different from the organisational or business operations (Hoffer, 2016). As shown in Table 1, most of the costs for BIM investment are reflected in the firm/ corporate level where the cost factors are needed to build the capability to run the projects using BIM process. Some cost factors are fixed costs that are needed to be spent for BIM implementation in general but there are also additional costs which subject to the specific goals to be achieved with BIM by different BIM users (Pena, 2011).

Table 1: Cost attributes related to BIM investment from previous literatures (Note: 1= Becerik-Gerber & Rice (2010), 2= Barlish & Sullivan (2012), 3= Giel & Issa (2013), 4= Stowe et al. (2014), 5= Hoffer (2016), 6= Jin et al. (2017), 7= Oesterreich & Teuteberg (2018), 8= Reizgevičius et al. (2018) , 9= Hong et al. (2019), 10= European Commission (2021)).

Cost related to BIM investment		**Literature**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Organisation level											
Cost cluster ID	**Cost detail**										
C_1: Software related investment	Annual software licence fee/ software upgrade	x		x	x	x	x	x	x		x
	Interoperability solutions						x		x		
	Software customization and data modifications						x	x			
	Installation and configuration							x			
C_2: Hardware related investment	Hardware upgrade			x	x	x	x	x	x		x
	Hardware maintenance	x									
C_3: Increased in labour/staff expenses	Staff training cost	x		x	x	x	x	x	x		x
	Cost on further instruction/guidance in new work methods					x					
	Labour cost increase (during pre-tendering, tendering and post award phase in public agency)							x	x		x
	VDC staff overhead			x							
	Cost for BIM manager/Technician/ IT support for assistance on BIM implementation					x				x	
	Cost for staff dealing with procurement							x			
C_4: Consultation cost	Consulting services for public procurement process in public agency										x
	Professional guidance for selection of BIM tools							x		x	
C_5: Infrastructure cost	Cost for changes in storage, workplace design, connectivity, etc	x				x		x			
C_6:	Project schedule delay									x	

Cost related to BIM investment		Literature									
		1	2	3	4	5	6	7	8	9	10
Adaptation cost	Reduce working efficiency, workflow disruption					x				x	
	Cost associated to project communication issues									x	
	Productivity loss during training							x	x		
	Cost of change management (eg; employee motivation)							x			
	Cost of organisational and business process restructuring (BPR)					x		x			
	Cost of staff turnover							x			
C_7: BIM implementation development cost	Custom 3D library development						x		x		
	Standard development and customization					x		x			
	Maintenance of BIM model and BIM central files									x	
Project level											
C_8: Extra charges incurred to client/public entity	Design phase cost/ BIM model creation (by designer/BIM modeller)		x								x
	BIM coordination cost (by BIM specialist)										x
	Construction cost (% of initial contract for BIM services by contractor)		x	x							

2.3 BIM Benefit Attributes

There are five benefits related to BIM investment that were most reported in literatures which are ‘schedule reduction and compliance’, ‘improved productivity’, ‘reduced Request for Information (RFI)’, ‘reduced rework’ and ‘reduced change order or variation order (VO)’ (Sompolgrunk et al., 2021). However, there is a significant gap in discussions by previous studies about intangible benefits such as ‘improved safety’, ‘improved project quality’, and others (Sompolgrunk et al., 2021).

Most benefits reported revolves around financial analysis and do not cover other aspects such as social and environment. Economic aspects of BIM benefits discussed direct and indirect cost savings in project such as reducing capital costs and operation costs for investors throughout asset whole lifecycle (Carvalho et al., 2019; Reizgevičius et al., 2018). For environmental aspects of BIM benefit, the factors include minimization of environmental impacts related to material waste, carbon footprint etc as part of the ‘green building’ concept (Reizgevičius et al., 2018; Zulkefli et al., 2020). On the other hand, benefits related to social aspects are usually achieved indirectly through improvements on project and building operation that could eventually upgrade other areas such as occupant’s health and accessibility which in turn will produce healthy communities (Carvalho et al., 2019; Mohammed, 2022).

Identifying and realizing BIM benefits are not simple. This is due to the complexity of the benefits which consist of ranges of rippled effects of direct, indirect, intermediate and end benefits (Oesterreich & Teuteberg, 2018; PwC, 2018a; Sanchez & Hampson, 2016). Moreover, the synergistic relationships between the enablers to the resultant changes and the benefits expected are often interrelated and not linear (Oesterreich & Teuteberg, 2018; PwC, 2018b; Sompolgrunk et al., 2021) which can lead to double counting.

Therefore, these benefits should not be analysed independently due to the dynamic and complex nature of BIM impact (Oesterreich & Teuteberg, 2018). The benefits of BIM should be clustered by taking account into different types of benefit factors, enablers, and stakeholders (actors/ beneficiaries). Different studies done previously have clustered BIM benefits in different ways. Gurevich & Sacks (2017) produced a complete impact map chart which listed eight (8) main organisation enablers and one hundred and eighty-eight (188) different activities performed by seven (7) types of stakeholders for BIM adoption in public agency. On the other hand, PwC (2018a) has provided eight (8) categories of end-benefits with hundred seventeen (117) impact pathways consists of different enablers in seven (7) project life cycles. European Commission (2021) has clustered BIM benefits into cost reduction attributed to many factors, time saving, and carbon dioxide (C02) emission reduction without much attention to influencing variables. Sanchez & Hampson (2016) presented thirty-one (31) types of end-benefits with a total of forty-seven (47) enablers in different project phases. These benefits were also linked to different BIM users.Table 2 presents the benefit attributes presented in the benefit dictionaries by Sanchez & Hampson (2016) with respect to the designer as the beneficiary. There are twenty-one (21) benefits listed and it was further categorised in this study based on two main enablers which are the ‘design review’ and ‘automated clash detection’ BIM uses.

Table 2: Benefit related to BIM investment adopted from Sanchez & Hampson (2016).

Benefit related to BIM investment Benefit cluster ID		Definition	BIM uses Design Review	Automated Clash Detection
B_1	Better change management	Management of changes to the design are more efficient and effective		*
B_2	Better data/information capturing	Information is captured easier, faster, and more accurately through a single 3D database		
B_3	Better environmental performance	Use of resources and cost are optimized through environmental performance measures		
B_4	Better scenario and alternatives analysis	Simulation processes are more productive, faster, and less prone to error.	*	
B_5	Better use of supply chain knowledge	Knowledge management is more effective and efficiently used	*	
B_6	Competitive advantage	Current services and profitability are improved for organizations to be superior in business position		
B_7	Faster regulation and requirement compliance	Less time required to achieve compliance in regulations and client's requirements		
B_8	Fewer errors	Reduced total number of errors and omissions		*
B_9	Higher customer satisfaction	Higher satisfaction of clients with project outputs		
B_10	Improved communications	Communication between stakeholders is more accurate, effective, transparent, and timely	*	*
B_11	Improved coordination	Coordination of documentation, processes and tasks between disciplines are more effective	*	*
B_12	Improved Data and Information Management	Data and information are more interoperable and long lasting for easier found, queried, and used		
B_13	Improved Documentation Quality and Processes	Complete and accurate documentation can be produced faster with less effort		
B_14	Improved efficiency	Reduced resources and time to complete tasks		
B_15	Improved information exchange	The availability of current project information is enhanced within and between organizations and individuals		
B_16	Improved learning curve	Faster learning of tasks		
B_17	Improved output quality	Design intents are reflected more accurately to non-technical stakeholders and more accurate 2D drawings derived from 3D model	*	*
B_18	Improved productivity	Man-hours required to carry out a task are reduced		
B_19	Less rework	Rework due to errors, omissions, and inefficient process are reduced		*
B_20	Lower cost	Cost is reduced from reduction of time to produce certain number of drawings, cross-checking documents, options creation etc.	*	*
B_21	Reduced execution time and lead times	Time required to complete delivery and latency between initiation and execution is reduced		

3. METHODOLOGY

3.1 Survey Development

According to previous literatures, there appears to be no consistent value of BIM (Sompolgrunk et al., 2021) despite of the great amount of evidence in the literature with respect to BIM benefits. This knowledge gap has driven this study to determine more accurate BIM cost and benefit attributes according to predetermined variables classified by (Mohamed et al., 2023). On that account, it is wise to first enumerate the variables involved to scope this study down.

Fundamentally, this research is revolved around public sector which is the Malaysian PWD as both the beneficiaries and the investor of BIM adoption. Consequently, an extensive literature review and preliminary interview sessions have been conducted to determine the extent of BIM adoption in Malaysian PWD. This includes the types of BIM activities done in most of BIM projects that could be evaluated in terms of its costs and benefits attributes. Among ten (10) BIM uses that were outlined in the PWD BIM Guidelines (JKR, 2014), only two (2) BIM uses were chosen as significant and matured by practice to influence enough value as shown in Figure 1. These were 'design review' and 'automated clash detection'. Hence, the BIM cost and benefits attributes in this study is determined based on these two specific uses only.

BIM benefit attributes were adopted from Sanchez & Hampson (2016) benefit dictionaries where nine (9) benefits were listed as the benefits resulted from both 'design review' and 'automated clash detection' activities in preconstruction phase as shown in Table 2. On another hand, BIM cost attributes were compiled based on the extensive literature review and were grouped into another eight (8) categories with respective subcategories as shown in Table 1.

The survey questionnaire was designed in three (3) sections. Section A included questions about respondent's background to assess respondent's reliability and to track down their working department. Section B consisted of a list of BIM benefit attributes acquired by the department from both Design Review and Automated Clash Detection activities in separate column. Section C proceeded to list down the BIM cost attributes that were spent for both activities to realize the benefits agreed. The respondents were asked to rank their answer based on the 5-points Likert's interval scale that anchors frequency between 1-strongly disagree and 5-strongly agree in section B and frequency between 1-very low and 5-very high for section C.

The content validity of the survey questionnaire was determined through the preliminary interview session with 4 BIM experts in different departments of Malaysian PWD to choose only the most relevant BIM costs and benefit attributes in their current level of BIM implementation. Based on the expert's comment, several BIM cost attributes were discarded on account to its relevance to Malaysian PWD and their current expenditures. These are C_4 and C_6.

3.2 Data Collection and Sampling

The survey questionnaire was disseminated directly to four (4) design departments in Malaysian PWD Headquarter (HQ) office which includes the architecture department, civil and structural engineering department, mechanical and electrical engineering department, and lastly the BIM unit from the Integrated Asset Management Branch. The sample was chosen using non-probability purposive sampling method due to the lack of sampling frame for BIM practitioners in public agency that have performed both BIM activities (Munianday et al., 2022). While it is a popular understanding among researchers that SEM-PLS can be used with small number of samples, it is however subjected to the nature of population and its heterogeneity (J. F. Hair et al., 2019).

According to the rule of thumb by Roscoe (1975), a minimum of thirty (30) samples from different subgroup is enough provided that it should be ten (10) times greater than the number of variables. With respect to PLS rule of thumb, the suggested minimum sample size is ten (10) times the number of the most complex dependent LV or the largest number of formative indicators (Ali Memon et al., 2020; Jr., J. F. Hair et al., 2016). On top of that, A-priori sample size power analysis was done using G*power tool to determine the minimum sample size for medium statistical power effect in a simple SEM model. Referring to Ali Memon et al. (2020), the input parameters used were effect size at 0.15 (medium effect), α at 0.05, power at 0.80 and the number of predictors at 7 in the input parameters generating 103 as the minimum sample size. Therefore, the minimum sample size targeted in this study was 103.

A total of 150 questionnaire forms were distributed to four (4) departments of Malaysian PWD. As a response, 103 completed questionnaire sets were received, of which six (6) questionnaire sets were incomplete and considered inappropriate. Henceforth, only 97 valid responses were used for the analysis.

The Statistic Package for the Social Sciences (SPSS) version 27.0 was used to conduct descriptive analysis on respondent's background. Table 3 shows participation level from different departments where respondents from civil and structural engineering department has the highest number of respondents which are 40.4 percent. Of the respondent's working experience, majority of them have one (1) to five (5) years of experience handling BIM projects. This is relevant since BIM implementation is still progressing in the public sector. However, the respondents reflect great experience with more than 50 percent having more than ten (10) years of experience working in the construction background. Majority of the respondents are professionals, and this indicates that the participants in the survey are competent.

To confirm the inexistence of Common Method Bias (CMB) issue, a full collinearity test was performed as recommended by Kock (2015). Using SmartPLS 4.0 software (Ringle et al., 2022), the all factor-level full collinearity VIF values were below 3.3 indicating that the CMB was not an issue in the dataset (Kock, 2015). Therefore, the data could be further analysed safely as the results suggest that CMB does not affect this study data.

Table 3: Descriptive analysis of respondent's background.

Characteristics	Category	Frequency	Percentage (%)
Designation	Middle Management	2	2.1
	Professional	56	59.6
	Technical	36	38.3
Department	Architecture Dept	7	7.4
	Civil and Structural Engineering Dept	38	40.4
	Mechanical and Electrical Engineering Dept	31	33.0
	Integrated Asset Management Branch (BIM Unit)	18	19.1
Working experience in industry	1-5 years	17	18.1
	5-10 years	25	26.6
	More than 10 years	52	55.3
Working experience in BIM	1-5 years	75	79.8
	5-10 years	15	16.0
	More than 10 years	4	4.3
Total		97	100

3.3 Conceptual Model

In assessing BIM benefit attributes and cost attributes that influences it, confirmatory composite analysis (CCA) in PLS-SEM was chosen as a method of confirming measurement quality (MCMQ) (J. F. Hair et al., 2020; Schuberth, 2021). Referring to the conceptual model of this study, the composite measurement model to be confirmed involves two (2) main constructs namely the BIM cost attribute and BIM benefit attribute.

This model will be analysed as a multi-group analysis with 'BIM uses' included as the controlled variables as a standard of comparison for both constructs (J. F. Jr. Hair et al., 2022). Thus, BIM cost and benefit attributes will be analysed in two (2) sets which are the 'Design Review' as set A and the 'Clash Detection' as set B as it hypothetically could influence different results (Mohamed et al., 2023).

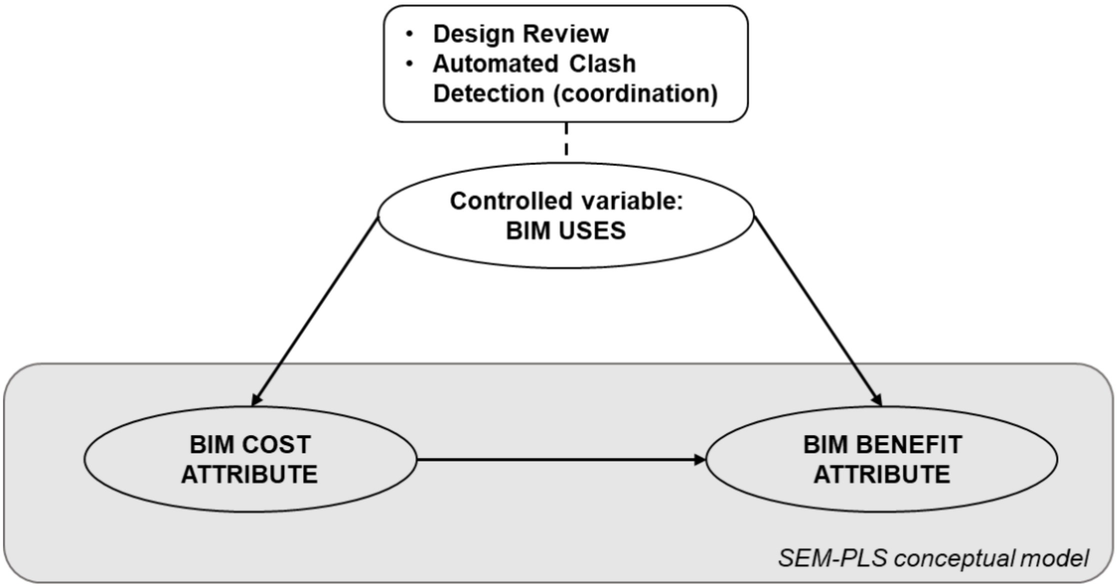

Figure 2: Predetermined variables in PLS-SEM conceptual model's context (Source:Author).

The BIM benefit latent variable were reflectively constructed. The reflective indicators are the manifestations of BIM benefits and may correlate to each other or may be interchangeable (J. F. Jr. Hair et al., 2022). This is corresponding to the dynamic and interrelating nature of BIM benefits and costs (Oesterreich & Teuteberg, 2018). However, this study uses the higher order construct (HOC) to minimize the complexity of the model (Tehseen et al., 2017). The reflective-formative type II second-order construct is developed for BIM cost composite variable since each BIM cost subset represents a separate concept and merged to mediate the influence on endogenous LV which is the BIM benefit (Becker et al., 2012; J. F. Jr. Hair et al., 2022; Tehseen et al., 2017). BIM cost attribute were formatively constructed which was composed of 8 lower order constructs with reflective indicators. Thus, CCA using PLS-SEM is an ideal solution as a statistical analysis to evaluate the quality of formative and reflective measurement models (Mohamad et al., 2014; Urbach & Ahlemann, 2010).

4. DATA ANALYSIS

The developed PLS-SEM model was drawn in SmartPLS 4.0 software (Ringle et al., 2022). Since the model was conceptualized as reflective-formative type II Hierarchical Component Model (HCM) as shown in Figure 2, the repeated indicator approach was used to validate and assess the model (Sarstedt et al., 2019). The HOC of 'Cost of BIM' was constructed by specifying a LV that represents all the indicators of the underlying LVs which are C_1, C_2, C_3, C_5, C_7 and C_8. This method was chosen for reflective-formative HCM as recommended by Becker et al., (2012).

The first step was done by assigning all indicators of the lower-order components to the higher-order components to run the evaluation of measurement model in lower order constructs. The scores were saved and added as new variables to the dataset. This is used as indicators for the step two of evaluation of measurement model in higher order constructs.

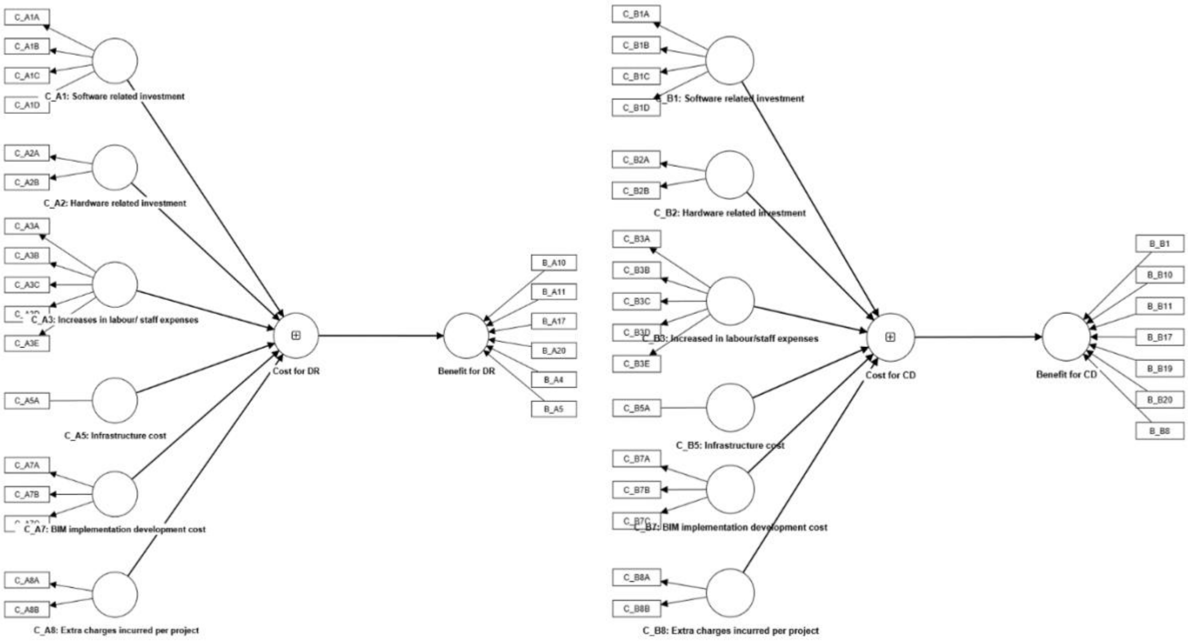

Figure 2: HCM for both 'Design Review' and 'Clash Detection' set respectively.

5. RESULTS AND DISCUSSION

5.1 Lower Order Measurement Model Evaluation

The measurement model was evaluated for reflective models in the lower order constructs regarding the reliability and validity of the indicators. For reflective measurement model, the reliability of indicators relative to its LV is calculated according to the outer loadings of the indicators (Memon & Rahman, 2014). The recommended loadings are above 0.708, however, indicators that have loadings below 0.708 should be considered for removal if it increases the value of CR or AVE above the suggested threshold value (Jr., J. F. Hair et al., 2016; Henseler et al., 2009; Memon & Rahman, 2014).

The second step was to assess the internal consistency reliability using Cronbach's Alpha (CA) and Jöreskog's composite reliability (CR) rho_c value for lower and upper bound respectively (J. F. Hair et al., 2019). These values indicate how well the indicators measuring the same LV are consistent and are associated with each other. Composite reliability value between 0.60 to 0.70 is acceptable, 0.70 to 0.90 is satisfactory to good (J. F. Hair et al., 2019; Urbach & Ahlemann, 2010).

The third step was to test the convergent and discriminant validities by looking at the Average Variance Extracted (AVE) value, heterotrait-monotrait ratio (HTMT) of correlations and Fornell-Larcker criterion. AVE evaluates the extent to which the indicators of a LV converge in comparison to other indicators that measure other LV (Urbach & Ahlemann, 2010). AVE value below than 0.50 shows that the LV consists of measurement residual (Mohamad et al., 2014) and is not acceptable whereby AVE of 0.50 or higher shows that the LV explains 50 percent or more of the indicator's variance (Jr., J. F. Hair et al., 2016).

On the other hand, HTMT measures the empirical distinction between different LVs to assess discriminant validity (Jr., J. F. Hair et al., 2016). The threshold value for HTMT is 0.90 for LVs that are similar conceptually and 0.85 for LVs that are conceptually more distinctive. Another measure used to test discriminant validity is using the Fornell-Larcker criterion where the square root of the AVE value of each construct should be greater than its highest correlation with other constructs (J. F. Jr. Hair et al., 2022).

Table 4 shows the result iterated for both 'Design Review' and 'Clash Detection' sets. All indicators in the lower order constructs were retained as the outer loading values were above 0.708. The constructs have good reliability as all CA and CR values were above the recommended value, which is 0.70. Besides that, AVE values were all above 0.5, which indicates a satisfactory level of convergent validity.

Table 4: Internal consistency reliability and convergent validity results for lower order constructs.

Set	**Construct**	**Indicator**	**Scale**	**Final results**			
				Outer loading	**CA**	**CR**	**AVE**
Design Review	C_A1: Software related investment	C_A1A	Reflective	0.832	0.914	0.940	0.795
		C_A1B	Reflective	0.899			
		C_A1C	Reflective	0.930			
		C_A1D	Reflective	0.904			
	C_A2: Hardware related investment	C_A2A	Reflective	0.880	0.755	0.890	0.803
		C_A2B	Reflective	0.912			
	C_A5: Infrastructure cost	C_A5A	Reflective	1.000	-	-	-
Clash Detection	C_B1: Software related investment	C_B1A	Reflective	0.855	0.925	0.947	0.818
		C_B1B	Reflective	0.907			
		C_B1C	Reflective	0.934			
		C_B1D	Reflective	0.920			
	C_B2: Hardware related investment	C_B2A	Reflective	0.906	0.805	0.911	0.837
		C_B2B	Reflective	0.924			
	C_B5: Infrastructure cost	C_B5A	Reflective	1.000	-	-	-

Table 5: Discriminant validity results for 'Design Review' set.

HTMT			
	C_A1: Software related investment	C_A2: Hardware related investment	C_A5: Infrastructure cost
C_A1: Software related investment			
C_A2: Hardware related investment	*0.927*		
C_A5: Infrastructure cost	0.287	0.305	
Fornell-Larcker Criterion			
	C_A1: Software related investment	C_A2: Hardware related investment	C_A5: Infrastructure cost
C_A1: Software related investment	**0.892**		
C_A2: Hardware related investment	0.773	**0.895**	
C_A5: Infrastructure cost	0.277	0.275	**1**

As for the discriminant validity, Table 5 and Table 6 reported the HTMT and Fornell-Larcker criterion results for 'Design Review' and 'Clash detection' sets respectively. The HTMT results for 'Design Review' set revealed a value above 0.90 between C_A1 and C_A2 LVs which possibly indicates an issue with the discriminant validity among them. Although J. F. Jr. Hair et al. (2022) assumes that the threshold value of 0.9, but also recommended bootstrapping procedure to test on the bootstrap confidence interval to derive the distribution of the HTMT statistic. The results of bootstrapping with 95% level of confidence show that the lower bound and upper bound was 0.780 and 1.104 respectively. Hence the HTMT value of 0.927 falls into the range of threshold with 5% error probability justifying the establishment of discriminant validity among the LVs. Furthermore, C_A1 and C_A2 are conceptually similar but still differ in terms of items of expenditure in theoretical concept (Becerik-Gerber & Rice, 2010; European Commission, 2021; Giel & Issa, 2013; Hoffer, 2016; Jin et al., 2017; Oesterreich & Teuteberg, 2018; Reizgevičius et al., 2018; Stowe et al., 2014).

Table 6: Discriminant validity results for 'Clash Detection' set

HTMT			
	C_A1: Software related investment	C_A2: Hardware related investment	C_A5: Infrastructure cost
C_A1: Software related investment			
C_A2: Hardware related investment	0.900		
C_A5: Infrastructure cost	0.439	0.448	
Fornell-Larcker Criterion			
	C_A1: Software related investment	C_A2: Hardware related investment	C_A5: Infrastructure cost
C_A1: Software related investment	**0.904**		
C_A2: Hardware related investment	0.779	**0.915**	
C_A5: Infrastructure cost	0.422	0.405	**1**

5.2 Higher Order Measurement Model Evaluation

In this study, the HOC consists of only formative constructs. For formative measurement model, different approach is required for assessment as more attention is needed to assess the collinearity of indicators whereby high collinearity among formative indicators are not good as they do not share a common theme, not interchangeable and is significant as an item towards its construct (Coltman et al., 2008). This is measured using Variance Inflation Factor (VIF). The suggested value is between 0.20 and 5.0 whereby results other than that implied for indicator removal, merging, or the need to create a higher order construct (Mohamad et al., 2014). However, according to Jr., J. F. Hair et al. (2016), an ideal VIF value is less than 3 while (Urbach & Ahlemann, 2010) reported that values below 10 are still acceptable.

The assessment of indicators weight's statistical significance using bootstrapping was done and indicators with a non-significant weight should be eliminated if the loading value is also not significant (J. F. Hair et al., 2019). Significant value (*p*-value) below 0.05 is the recommended value to indicate the statistical significance of the indicators (J. F. Hair et al., 2019; Urbach & Ahlemann, 2010), but values lower than 0.10 may be justifiable with small sample size (J. F. Hair et al., 2020). It can also be evaluated using *t*-value of the outer weight which should be above 1.96 for 5% significance level (two-tailed test) (Jr. , J. F. Hair et al., 2016). Indicators with non-significant weight with loading more than 0.5 can be retained as it indicates sufficient absolute contribution to the LV (Jr. , J. F. Hair et al., 2016).

VIF values were liberally accepted although some exceeds 3 due to the nature of interrelated and complexity of BIM benefit (Oesterreich & Teuteberg, 2018). Hence, certain collinearity was expected from completely different concept of benefits. For example, VIF more than 5 in B_B11 indicates collinearity issues, B_B10 and B_B11 could be merged to treat multicollinearity problem, however, based on theoretical background, both benefits possess different source and nature of impact (Sanchez & Hampson, 2016), so both were retained as separate indicators.

In terms of significance of indicators, Table 7 reported insignificant value from the all indicators in the formative model due to the *p*-value of more than 0.05 as well as *t*-value of lower than 1.96. However, this study adopts the decision-making process suggested by J. F. Jr. Hair et al. (2022) to retain the indicators that have outer loading values of more than 0.5.

The final HCM for both sets are illustrated in Figure 3 and 4. For Design Review set, only three (3) constructs for cost of design review were retained which are the C_A1, C_A2 and C_A5 while five (5) constructs for benefit of design review were deemed as relevant which are the B_A10, B_A11, B_A17, B_A20 and B_A4. On the other hand, for Clash Detection set, three (3) similar constructs for cost of clash detection were retained while six (6) constructs for benefit of design review were included in the model which are B_B1, B_B10, B_B11, B_B17, B_B19 and B_B8.

Table 7: Collinearity and statistical significance for higher order constructs (Note: Two-tailed percentile bootstrapping test based on 1,000 subsamples at 5% significance level (2.5%, 97.5%); PCI: Percentile Confidence Interval).

Construct	Indicator	Scale	Final result					
			VIF	*p*-value	*t*-value	PCI:2.5% confidence interval	PCI:97.5% confidence interval	Loading
Design Review								
CDR: Cost for Design Review	**C_A1**	Formative	2.505	0.409	0.826	-1.340	1.626	0.957
	C_A2	Formative	2.505	0.828	0.218	-1.327	1.621	0.835
	C_A3	Formative	OMITTED					
	C_A5	Formative	1.097	0.560	0.584	-0.501	1.023	0.519
	C_A7	Formative	OMITTED					
	C_A8	Formative	OMITTED					
BDR: Benefit for Design Review	**B_A10**	Formative	3.271	0.260	1.126	-0.314	1.814	0.924
	B_A11	Formative	3.275	0.798	0.257	-1.423	1.283	0.743
	B_A17	Formative	2.807	0.242	1.171	-0.213	1.536	0.890
	B_A20	Formative	1.926	0.947	0.066	-1.229	1.235	0.555
	B_A4	Formative	2.269	0.709	0.374	-1.122	0.821	0.588
	B_A5	Formative	OMITTED					
Clash Detection								
CCD: Cost for Clash Detection	**C_B1**	Formative	2.618	0.223	1.220	-1.071	1.739	0.995
	C_B2	Formative	2.580	0.938	0.078	-1.390	1.457	0.758
	C_B3	Formative	OMITTED					
	C_B5	Formative	1.241	0.794	0.261	-0.736	0.905	0.503
	C_B7	Formative	OMITTED					
	C_B8	Formative	OMITTED					
BCD: Benefit for Clash Detection	**B_B1**	Formative	2.327	0.680	0.412	-0.972	1.371	0.780
	B_B10	Formative	*4.885*	0.776	0.285	-1.675	1.504	0.849
	B_B11	Formative	*5.067*	0.654	0.449	-0.925	1.448	0.908
	B_B17	Formative	2.869	0.957	0.054	-1.190	1.117	0.762
	B_B19	Formative	1.934	0.697	0.389	-1.051	0.556	0.599
	B_B20	Formative	OMITTED					
	B_B8	Formative	3.328	0.315	1.006	-0.314	1.555	0.922

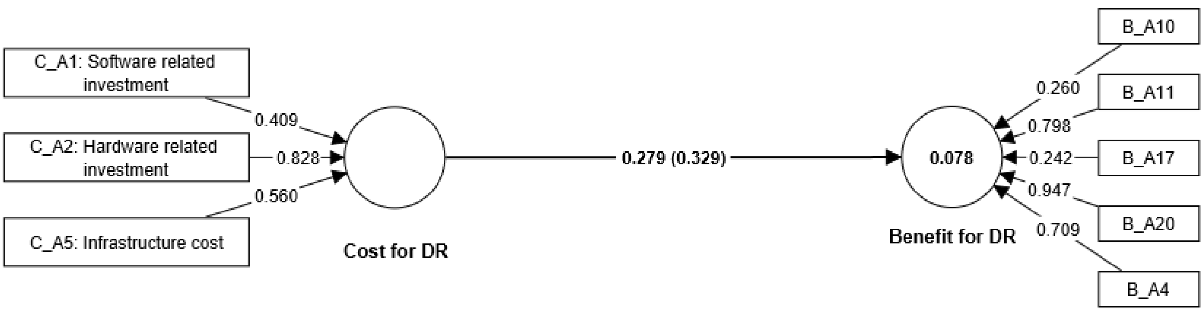

Figure 3: Final HCM for 'Design Review' set.

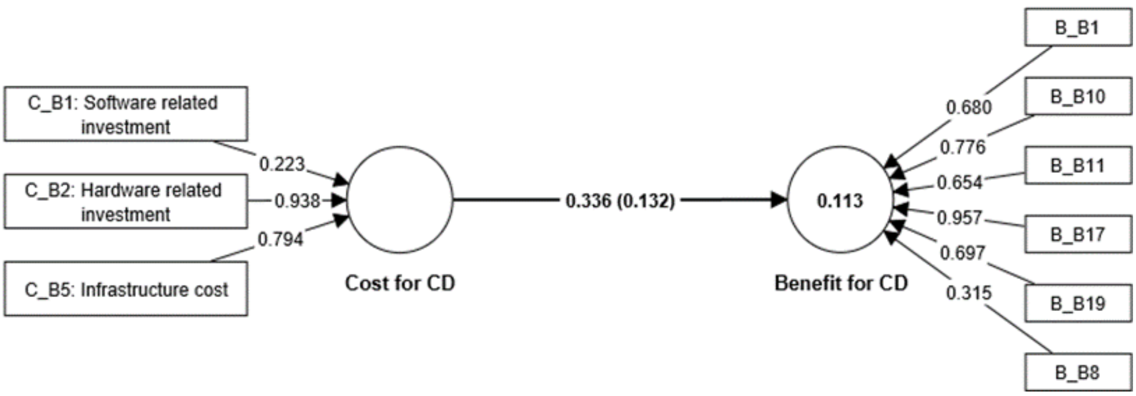

Figure 4: Final HCM for 'Clash Detection' set.

It could be summarized here that C_1: Software related investment, C_2: Hardware related investment, and C_5: Infrastructure cost were the cost attributes that are needed to realize the benefits of BIM resulted from design review and clash detection activities. The benefits realized were B_10: Improved communication, B_11: Improved coordination, B_17: Improved output quality, B_20: Lower cost, B_4: Better scenario and alternatives analysis, B_1: Better change management, B_19: Less rework, and B_8: Fewer errors. The benefits perceived to have been realized in Malaysian PWD is illustrated in Figure 5.

This paper investigated the benefit and cost attributes involved in BIM implementation limited to only two (2) different BIM uses which are the design review and automated clash detection during the design stage. The structural model of the HCM and the path coefficient between the cost and benefit LVs were not discussed as the aim of this study was achieved.

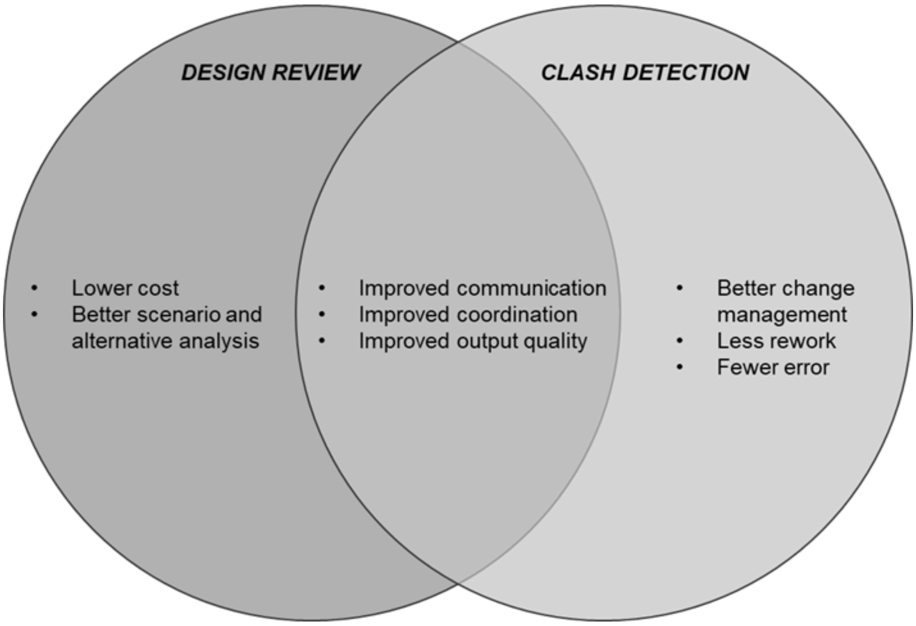

Figure 5: BIM benefit attributes in both 'design review' and 'automated clash detection' activities.

6. CONCLUSION AND IMPLICATIONS

The objective of this study is to determine BIM benefit attributes according to different BIM activities and to discover BIM cost attributes that will influence the realization of previous BIM benefits. The findings of this study confirm the cost and benefit attributes both activities through Confirmatory Composite Analysis (CCA) as a method of confirming measurement quality (MCMQ) in Partial Least Square Structural Equation Modelling (PLS-SEM).

This study contributes to a multi-faceted understanding of BIM adoption, value assessment, and benefit measurement within the context of the public sector's influence. The research underscores the pivotal role played by the public sector in driving the adoption of BIM practices within the construction industry. The implications of this observation are twofold. Firstly, it emphasizes the growing recognition of BIM's potential to overcome conventional inefficiencies in the construction domain. Secondly, it underscores the importance of government-led initiatives in fostering BIM adoption, thereby fostering innovation and efficiency in the construction sector.

The study delves into the challenges surrounding the measurement of BIM's value and benefits. By highlighting the discordance between perceived benefits and costs associated with BIM, the research signals the need for a comprehensive and standardized approach to evaluating the worth of BIM investments. The implications extend to the development of applied methodologies that systematically measure and validate the advantages brought about by BIM implementation. This shift towards structured measurement aligns with industry demands for reliable methods to assess the tangible benefits of BIM adoption.

The study also highlights the existence of diverse tools and techniques for quantifying BIM's value, such as Return on Investment (ROI) and Cost-Benefit Analysis (CBA). However, the lack of consistency in reported values across different studies reveals the need for industry-standard benchmarks to facilitate more accurate comparisons. The implications of this observation underscore the significance of a systematic approach to measuring BIM benefits. The study's findings suggest that the development of controlled variables and a structured framework for benefit measurement could significantly enhance the accuracy and reliability of BIM valuation efforts.

This study provides theoretical contribution in studies related to the approach of measuring BIM value through confirmation of key attributes of costs and benefits prior to empirical measurement of the attributes. Practically, the perceived cost and benefit attributes of BIM implementation can be utilized for simulations and measurement in case studies. By understanding different BIM cost and benefit attributes involved in BIM implementation, it could provide a more robust and accurate results of CBA to assist in better decision making for Value Management (VM) execution in Malaysian PWD.

6.1 Limitations and Directions for Future Research

Although this paper has produced and confirmed the cost and benefit attributes in Malaysian PWD, it has some limitations that should be acknowledged. First, it has a relatively small sample size of below 100 spanning across four (4) different departments as a single category of beneficiary. This is parallel to the state of BIM implementation within Malaysian PWD and limited number of respondents which has experienced performing both BIM uses outlined in this paper.

Second, this paper only examined cost and benefit attributed to two (2) types of BIM uses or enablers which are design review and automated clash detection based on current level and maturity of BIM implementation in Malaysian PWD. It may be expanded to other BIM uses such as quantity take-off, collaboration, energy analysis, digital fabrication, and others according to practices. Future studies may also take account for other variables to produce more comprehensive results such as implementation of BIM uses by different beneficiaries and in different project stages. Future research should aim to expand the scope of participants from a broader range of departments. Including a larger and more diverse sample would enhance the generalizability of findings and provide insights into potential variations in BIM adoption across different units.

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