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The Development of Building Information Modelling (BIM) Performance Model for the Malaysian Construction Industry

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Abstract: The concept of Building Information Modelling (BIM) has attracted greater attention in the Malaysian construction industry since its introduction in 2007. Several projects in Malaysia such as Pusat Kanser Negara and Convocation Hall, UTHM have adopted this concept. One of the benefits of BIM is the projection of a 3D image of the proposed building, which allows stakeholders to get a better idea of the actual building. BIM also improves the planning and design process of the project and thus the quality of the actual building. These advantages of the BIM concept are crucial for the success of the project. Despite the implementation and benefits of BIM, there are still uncertainties about the actual performance of organisations using BIM. This is because there are no evaluation tools or models in Malaysia that can evaluate BIM performance of BIM. Therefore, this study aims to develop a performance model for the implementation of BIM in the Malaysian construction industry. In this study, the AHP technique was used to collect data. The AHP results have successfully assigned weights to all BIM performance metrics. The consensus value also exceeds 50%, which confirms that the experts' agreement on the weighting of the metrics is acceptable. In conclusion, the proposed and developed BIM performance model could be useful to practitioners, especially the government and CIDB, in evaluating the performance of BIM organisations in the Malaysian construction industry. These measurement results could be a basis for future improvements for BIM organisations.

Keywords: BIM implementation, BIM performance

1. Introduction

Building Information Modeling (BIM) was first introduced to the Malaysian construction industry in 2007 by the Public Works Department (PWD) (Latiffi *et al*., 2013). The Malaysian construction industry has been trying to enhance its construction performance through the introduction of BIM (Othman *et al*., 2021). The BIM acts as a platform to allow various stakeholders to collaborate in the planning, design, and construction of buildings using 3D models (Lorek, 2018), hence, improving the performance of the industry. However, even after seven (7) years from its introduction, the BIM implementation level in the Malaysian construction industry is still low (Zahrizan *et al*., 2013; Enegbuma *et al*., 2014). Therefore, the Ministry of Works (KKR) and its agency, the Construction Industry Development Board (CIDB) Malaysia have worked together to enhance BIM implementation in Malaysia which eventually will boost the construction industry's productivity in Malaysia. One of the major strategies was BIM is highlighted as one of the technologies under Productivity Thrust in the Construction Industry Transformation Programme (CITP) 2016–2020. The CITP showed there are several KPIs that have been listed under the Technology Focus Area. For example, to implement BIM at least 40% of Level 2 in 2020 for 100% of public building projects above RM 100 million (for JKR building projects) and 70% of private and public building projects above RM 10 million will adopt BIM by Jan 2021 (CIDB, 2019). Hence, the CIDB

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and its subsidiaries have made efforts to promote BIM by carrying out various BIM-related programs such as BIM Day, BIM Road tours, incentives, seminars, workshops, and others to empower the usage of BIM in the Malaysian construction industry. The Malaysian Ministry, through the Strategic Plan 2021-2025 of the Public Works Department (PWD), has scheduled the mechanism's implementation to hit 50 % by 2021 and 80 % by 2025.

Despite all these efforts by public and private agencies to promote BIM in the Malaysian construction industry, there a little emphasis has been put to measure the BIM performance. Even though there are several existing models, and frameworks from others countries that have been developed to evaluate BIM performance, unfortunately, there are no standard forms (model) of evaluation in Malaysia. Developing a BIM performance model can ensure that the best practice of BIM in the organisation may be identified and expanded. Organisations can operate organisational evaluations to better understand what they can do or should change to improve their ability to perform. The evaluation can help organisations obtain useful data on their performance, identify important factors that support or inhibit their achievement of results and establish themselves with respect to competitors (Neely *et al*., 2005). Public and private clients have no mechanism to measure the BIM performance. Therefore, the main aim of this study was to develop a performance model to evaluate the BIM performance in the Malaysian construction industry.

2. Literature Review

2.1 Building Information Modeling (BIM) in Malaysia

In the Malaysian construction industry, Public Works Department (PWD) BIM has introduced in 2007 (Latiffi *et al*., 2013). Ding *et al*. (2014) described BIM as a model that offers a database that allows all project teams to retrieve the needed information through the same system upon delivering a project. The exploration of BIM by PWD was supported by the establishment of a BIM Committee within PWD. The purpose of this action was to identify a suitable BIM platform that could be used by PWD. The Committee proposed the use of Autodesk as one of the BIM tools (Latiffi *et al*., 2013). This proposal was made through the Information Technology Department. By the end of 2010, the installation of the BIM tool started in PWD, followed by the training in the use of the tool in early 2011. Established in 2012, the BIM Unit Project consists of architects, structural engineers, mechanical and electrical (M&E) engineers, and quantity surveyors. The purpose of this division is to produce a Families' Component, which is Revit Families for two pilot projects (Latiffi *et al*., 2014). The pilot projects are Type 5 Clinic (KK5) Sri Jaya Maran, Pahang and Administration Complex of Suruhanjaya Pencegah Rasuah Malaysia (SPRM) Shah Alam, Selangor (Latiffi *et al.*, 2013). BIM could be implemented in all construction project phases, namely the Pre-Construction phase, Construction phase, and Post-Construction phase (Furneaux & Kivit, 2008). It could be seen that BIM application in a construction project contributes to more effective project management. The ability of BIM to foster collaboration between construction players facilitates design process decisions (Azhar *et al*., 2012). Additionally, clash detection and clash analysis during the design stage are able to reduce time and construction costs. The BIM also ensures the completion of a quality construction project with its assistance in organising activities and phasing during the planning stage of a project (Azhar *et al*., 2012).

2.2 BIM Performance in Malaysia

The majority of the BIM implementation studies in Malaysia were only based on the benefits, challenges, awareness and readiness of BIM (Arif *et al*. (2021); Othman *et al*. (2021); Al-Ashmori *et al*. (2020); Kong *et al*. (2020); Roslan *et al*. (2019); Musa *et al*. (2019). However, there is a minimal study on BIM performance undertaken by the Malaysian construction industry due to the lack of knowledge in BIM performance evaluation. Malaysian BIM practitioners have difficulties understanding their BIM performance. Therefore, this study recommended that the BIM performance evaluation increase the BIM implementation level in Malaysia. The BIM performance should be evaluated rather than only promoting the advantages and the implementation benefits. It is essential to develop a BIM performance model to ensure that the best practice of BIM in Malaysia may be identified and expanded. Organisations can better understand what they can do or should change to improve their ability to perform in BIM implementation (Succar, 2013). As the management literature states, if you cannot measure something, then you cannot control, manage, and improve it (Garvin, 1993; Martin *et al*., 2009).

At the beginning of the study, preliminary interviews were conducted with two BIM experts from the BIM Unit in the Public Works Department (PWD) and one from MyBIM Centre, CIDB to determine if the BIM performance evaluation could be adopted for the Malaysian construction industry. In addition, to discover the evaluation scope suitable to Malaysia's context. According to Succar (2013), BIM performance can be evaluated based on individual, organisation, and project performance. Preliminary interview findings showed that the BIM performance evaluation can be adopted in Malaysia but could only be based on organisational performance. Evaluating BIM project performance was challenging, given that a limited project used the BIM process from pre-construction until post-construction. Most of the projects employed the BIM process solely during the design stage. Additionally, individual competency was challenging to evaluate due to the need for skilled BIM people in the Malaysian construction industry.

The preliminary interview also indicated that the Malaysian construction industry still does not have any specific evaluator to evaluate BIM performance. Zahrizan *et al*. (2013) indicated that the BIM level in the Malaysian construction industry is between 0 and 1. Based on the Bew-Richards and Succar model perspective, Enegbuma *et al*. (2014)

categorized the BIM level in Malaysia between stages 1 and 2 (Enegbuma *et al*., 2014). Even though many researchers have discussed the level of BIM implementation in Malaysia, most of the researchers concluded overall BIM implementation level is based on awareness and readiness in Malaysia (Othman *et al*., 2020). Besides, the level classification may not be relevant to use in Malaysia's context because the BIM level in Malaysia is still in the infancy stage. As Jayasena and Weddikkara (2013) stated, Bew-Richards and Succar level classifications were less proper in evaluating a BIM infant industry. Hence, the preliminary interviews found that the experts suggested that the classification of BIM performance should be described in words, and the description must be simple and understandable. The use of metal rating (GBI rating) or star rating (MyCREST rating) classification more preferred.

2.3 Existing BIM Performance Models

This study identified 13 BIM performance models that were developed to evaluate BIM performance around the world (McCuen & Suermann, 2007; Bew & Richard, 2008; Indiana University, 2009; Succar, 2009; Sebastian & Van Berlo, 2010; CPIc, 2011; Kam *et al*., 2013; Strategic Building Innovation, 2013; CICRP, 2013; Du *et al*., 2014; Giel & Issa, 2013; Liang *et al*., 2016; Yilmaz *et al*., 2019). The first BIM model was introduced in 2007, named BIM Interactive Capability Maturity Model (I-CMM). UK BIM Maturity Model followed it in 2008. In 2009, two models were developed to assess BIM performance: BIM Proficiency Matrix and BIM Maturity Matrix. In ten years, nine (9) models of the BIM performance model were established to respond to the BIM evolution around the whole world. These models were adopted to evaluate the BIM performance in the organisation.

Although many models were developed to evaluate BIM performance, most of them cannot be adopted for the Malaysian construction industry due to the different levels of BIM implementation compared to the other countries. Therefore, an expanded BIM performance model for the Malaysian construction industry is needed. The development of the BIM performance model should include the essential components relevant to Malaysia's BIM implementation.

2.4 Importance Components of BIM Performance Model

The initial step in developing a new performance model is to select the evaluation areas that should be included (Ali & Al Nsairat, 2009). The evaluation scope clarifies what will be evaluated, and it is vital to consider carefully what the evaluation needs to do before thinking through possible design. An evaluation of BIM implementation can focus on an individual, an organisation and a project (Succar, 2013). Consequently, several analyses upon previously established BIM performance models, such as BIM Interactive Capability Maturity Model (I-CMM), UK BIM Maturity Model, BIM Proficiency Matrix, BIM Maturity Matrix, BIM QuickScan, CPIx-BIM Assessment Form, VDC Scorecard, bimSCORE, Organisation BIM Assessment Profile, BIM Cloud Score (BIMCS), Owner BIM Competency Assessment Tool, Multifunctional BIM Maturity Model, and BIM Capability Assessment Reference Model (BIM-CAREM), had been carried out in the literature stage. The review is considered by far the most comprehensive method to develop a new performance model and evaluate BIM implementation in an organisation.

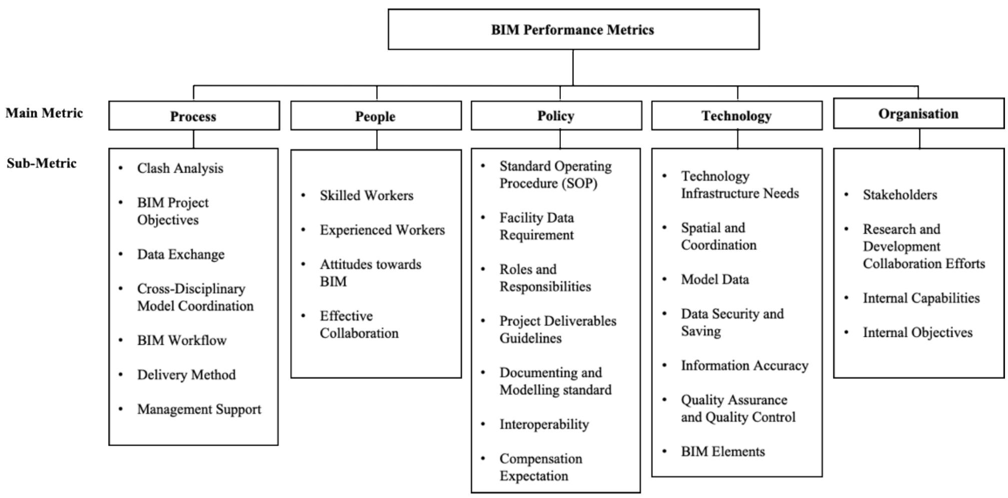

Fig. 1 - BIM performance metrics

The second component is BIM performance metrics. It should gauge the BIM evaluation scope of the organisation (Yilmaz *et al*., 2019). Literature showed that the development performance metrics depend on the objectives of the evaluation. In BIM, the term performance metrics have been identified in various contexts, but no general agreement exists. The existing BIM performance model defined the performance metrics as key performance indicators (KPI), a key metric, critical success factors, criteria, fields, domains/sub-domain, evaluation aspects/areas, categories, and divisions. Based on the review, technology, process, policy, people, and organisation had been found that appropriate performance metrics could be used to evaluate BIM implementation in various organisations, especially Architecture, Engineering, and Construction (AEC). These main metrics were further divided into sub-metrics as performance metrics might impact the BIM performance in an organisation (Figure 1). The sub-metrics were also compiled from the existing BIM performance model.

Following that, the next important component is the weight of the performance metrics. Once the performance metrics are identified, it needs to cull the number of performance metrics to a manageable number. According to Eckerson (2010), a performance metric must contain an actual number. The easiest way to do this is by weighting each metric to evaluate the performance. Every performance evaluation metric needs weightage to prioritise which metric is more important and greatly impacts the BIM implementation (Hamid M.F., personal communication, November 9, 2018). The availability of weights important to differentiate the level of important of a metric with another metrics. Hence, a BIM performance model should include the component in order quantifying the performance judgement.

The fourth important component is BIM performance level classification. The availability of performance metrics and their weightage were inadequate to evaluate BIM performance. They need to be classified to assess their performance. The level of classification provides the overall result of the evaluation. It also shows the achievement of an organisation implementing BIM. A BIM performance model must include the component, specifically BIM performance levels (Yilmaz *et al*., 2019).

3. Research Methodology

An Analytical Hierarchy Process (AHP) was employed as a research approach in this study to determine the weighting of BIM performance criteria. The AHP approach is an effective tool for calculating the weighting structure for various countries' construction appraisal programmes. (Chang et al., 2007; Ali & Al Nsairat, 2009; Meng *et al*., 2014; Chen & Li, 2015; Londoño-Pineda *et al*., 2021). The AHP was used due to the lack of information on the performance of BIM in the Malaysian construction industry. It aims to derive opinions from the perspective of BIM experts in the Malaysian construction industry. As BIM performance metrics are generally considered multi-dimensional criteria, a consensus-based approach is best suited to the development of comprehensive and effective evaluation categories and criteria (Das *et al*., 2010). In addition, a reliable weighting system needs to be developed to recognise and formalise the level of importance of the metric (Cole, 2005; Lee *et al*., 2002). Therefore, Analytic Hierarchy Process (AHP) is used to develop a suitable weighting system for the BIM performance metrics.

As the AHP technique relies on the expert judgement of moderate feedback throughout the process, the respondents included BIM experts from public and private organisations. Purposive sampling was used to choose responders based on three criteria: their position within the organisation, years of BIM expertise, and the number of BIM projects completed. In addition, the snowballing technique was employed to gather further information about BIM experts in the Malaysian construction industry. The data collection process dragged on for several months as it was difficult to find enough respondents. Therefore, the AHP surveys were distributed to 35 BIM practitioners across Peninsular Malaysia. However, the reluctance of invited respondents to participate in the study, citing that they could not contribute to the study as they would not fully participate in the BIM project. Consequently, only 20 practitioners completed and returned the questionnaire. The 20 respondents were still acceptable in AHP technique as in previous studies, the minimum sample size for the AHP survey was four (Akadiri *et al*., 2013; Chou *et al*., 2013; Pan *et al*., 2012; Li & Zou, 2011). The major advantage of the AHP is that it does not require a statistically significant (large) sample size to produce robust and statistically robust results (Doloi, 2008).

A structured survey form using AHP as data collection instrument was employed in this study to determine the preference of practitioners on structuring BIM performance metrics for the Malaysian construction industry. The method to collecting AHP survey using self-completion method; email surveys, WhatsApp, and SurveyMonkey.com to get feedback from respondents. Figure 2 shows the hierarchy model for BIM performance metrics.

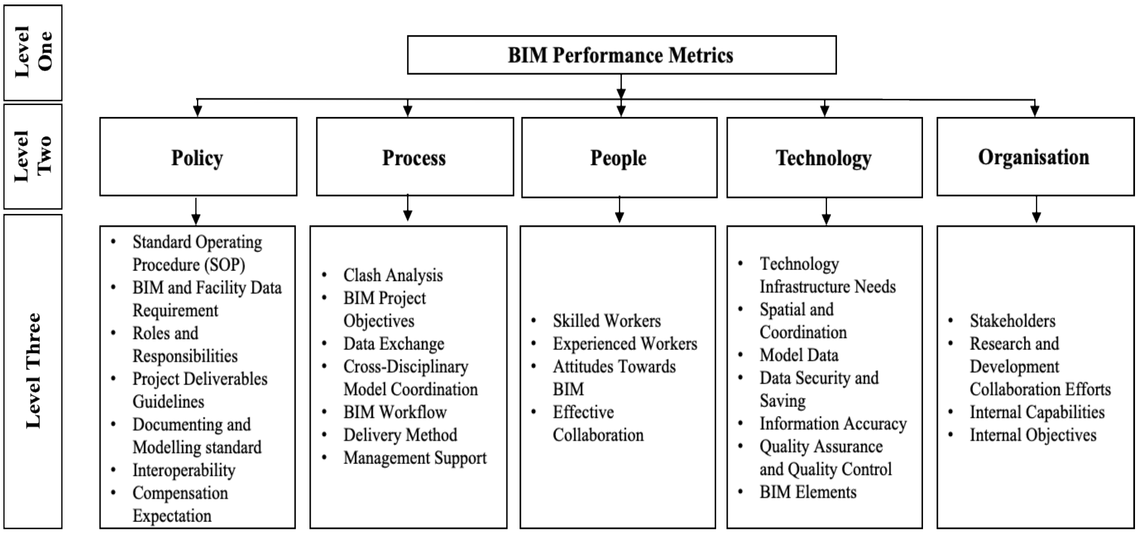

Fig. 2 - Hierarchy model for BIM performance metrics

The first level of the hierarchy model is the goal of the AHP. The AHP survey employed five main metrics (Level 2) and 29 sub-metrics (Level 3) as the elements to achieve the goal. In this sense, and with the decision purpose in mind, comparisons are done between the relative relevance of each two metrics at the second hierarchy level. Every two sub-metrics under the same main metric (at level two) are also compared, and so on. Table 1 illustrates an example of the characteristic weightage diagram of metrics comparison in the AHP survey.

Table 1 - Weightage diagram of BIM performance

Characteristics	← Weightage →																	Characteristics
Process	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Technology
Process	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organisation
Process	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	People
Process	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Policy
Technology	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organisation
Technology	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	People
Technology	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Policy
Organisation	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	People
Organisation	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Policy
People	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Policy

As depicted in Table 1, the first level (main metrics) of BIM performance metrics are rated using the pair-wise comparison. The scale runs from one (1) to nine (9) points, with one (1) indicating that the two factors are the same or have equal importance. In contrast, the number nine (9) denotes that one member in a paired matrix is far more important than the other. Meanwhile, Table 2 illustrates the scale applied to determining each weightage for the weightage diagram. Using the scale, each answer was analysed from the primary importance for each metric, in which the respondents compared its characteristics with the others to identify the BIM performance metrics. All the respondents presented different opinions regarding the importance of each characteristic. In this section, respondents were required to state and choose the suitable metrics that relevant to Malaysia according to their experience and knowledge. After all metrics have been compared with the priority scale by pair, a paired comparison or judgement matrix is performed.

Table 2 - The applied scale to determine the weightage (Saaty, 2000)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective

3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	Activity is strongly favoured over the other, with its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance		

Next, the survey findings were analysed using an AHP excel spreadsheet template developed by Goepel (2013), which assisted in analysing the metrics of BIM performance. The purpose of proposing the AHP excel spreadsheet template in this study is because it is accessible and able to ease the burden of calculating all the criterion matrices using the appropriate formula. The researcher can somehow insert the inputs and obtain their decision from the excel spreadsheet. Additionally, the template helps weight the performance metrics in an even shorter time. Besides easy- to-use, it also does not rely on external links to other workbooks.

4. Data Analysis

4.1 Respondent's Background

As this study applied purposive sampling to select experts. Before distributing the AHP survey, the researcher contacted the respondents via LinkedIn, email and WhatsApp to verify the respondents complied with the selection criterion. In conclusion, this study was able to get feedback from twenty (20) respondents. Table 3 provides detailed information related to the respondents.

Table 3 - Respondent's background

Resp	Sector	Organisation	Position	BIM Experience (Years)
R1	Private	Consultant	BIM Manager	8
R2	Private	Consultant	BIM Modeler	5
R3	Public	Public Works Department	Civil Engineer	6
R4	Private	Consultant	BIM Manager	5
R5	Private	Consultant	BIM Manager	5
R6	Private	Consultant	BIM Modeler	4
R7	Private	Contractor	BIM Manager	6
R8	Private	Consultant	BIM Modeler	5
R9	Private	Consultant	BIM Coordinator	5
R10	Public	Public Works Department	Civil Engineer	6
R11	Private	Consultant	BIM Modeler	5
R12	Private	Consultant	BIM Coordinator	5
R13	Public	Consultant	BIM Manager	5
R14	Public	Consultant	BIM Manager	5
R15	Private	Consultant	BIM Coordinator	6
R16	Private	Contractor	BIM Manager	5
R17	Private	Consultant	BIM Modeler	5
R18	Private	Consultant	BIM Leader	6
R19	Public	Public Works Department	Civil Engineer	6
R20	Public	Public Works Department	Civil Engineer	5

4.2 The AHP Data Analysis

According to Goepel (2017), there are two functions of AHP; weight calculation (hierarchy mode) and alternative evaluation (alternative mode) using the AHP eigenvector method. This study uses AHP to calculate and allocate weights to the selected main metric and sub-metrics of the BIM performance. The AHP can differentiate the important metric from the other metric by applying numerical weights that represent the relative importance of each BIM performance metric. Hence, the study used the five stages AHP by Saaty (1980) as shown in Figure 3.

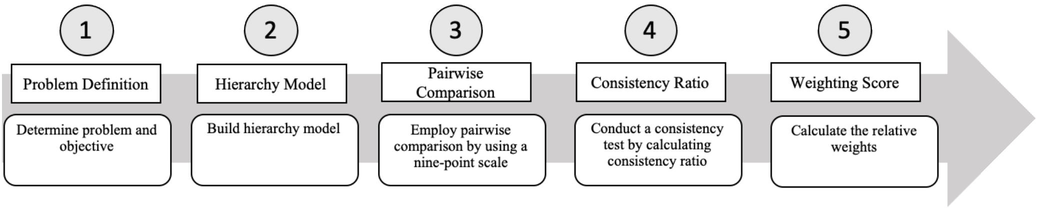

Fig. 3 - Five stages of AHP (Saaty, 1980)

Stage 1: Problem Definition

In stage 1, the research question and objectives were established. The research topic in this study was to develop a BIM performance model, with the goal of prioritising and assigning significant weightings to each of the BIM performance metrics.

Stage 2: Hierarchy Model

In Stage 2, to break down complex problems into manageable components, an AHP model was devised (Figure 4). Multiple hierarchical tiers were created. The top level of the hierarchy model was described as the problem's purpose of determining the subject matter's scope. The second level had categories, and the criterion levels were separated further. The top level for this study was the prioritising of the BIM performance metrics, which was followed by the BIM performance main metrics and sub-metrics at the bottom.

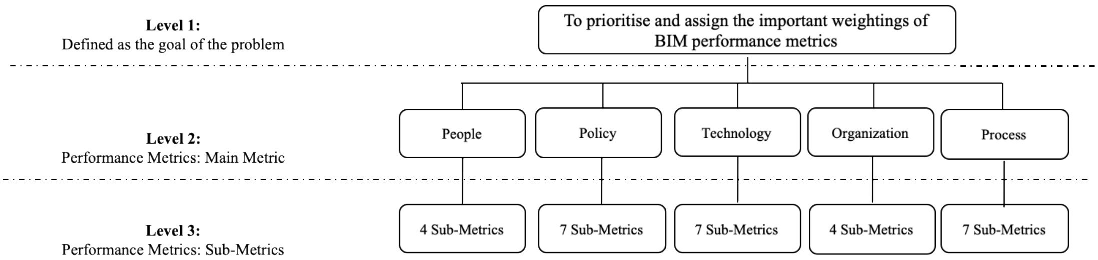

Fig. 4 - The hierarchy structure of BIM performance metrics

Stage 3: Pairwise Comparison

Furthermore, in Stage 3, the pairwise comparison used a mathematical structure designed to conduct a pair comparison of one category over another (Saaty, 1994). Criteria were appropriately compared in relation to the project goal. All pairwise comparisons are saved internally in the format

$$pwc = (a_{1,}a_{2,} \dots a_{npc}), (x_{1,}x_{2,} \dots x_{npc}) \quad (1)$$

With integers $a_i \in [0,1]$, $x_i \in [1,M]$, M = 9 and i = 1 ... npc with npc is the number of pairwise comparisons.

$$npc = \frac{n^2 - n}{2}. \quad (2)$$

For n criteria the n x n decision matrix is then filled from pwc. For $a_i = 0$ we take $a_i = 1$, for $a_i = 1$ we have to take the reciprocal of x_i. For example, for three criteria with pwc = (0,0,1), (3, 5, 7) the decision matrix is

$$\mathrm{M} = \begin{pmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & \frac{1}{7} \\ \frac{1}{5} & 7 & 1 \end{pmatrix} \quad (3)$$

By using Goepel AHP Template, the list of performance metrics was compared to each criterion separate into five main metrics; Process, Policy, People, Technology, and Organisation. The pairwise importance of the sub-metrics was compared in accordance with the other sub-metrics only for the same main metrics. Hence, there were seven sub-metrics for Process, seven sub-metrics for Policy, seven sub-metrics for Technology, four sub-metrics for People, and four sub-metrics of Organisation. Figure 5 illustrated the example of pairwise comparison of five main metrics of BIM performance.

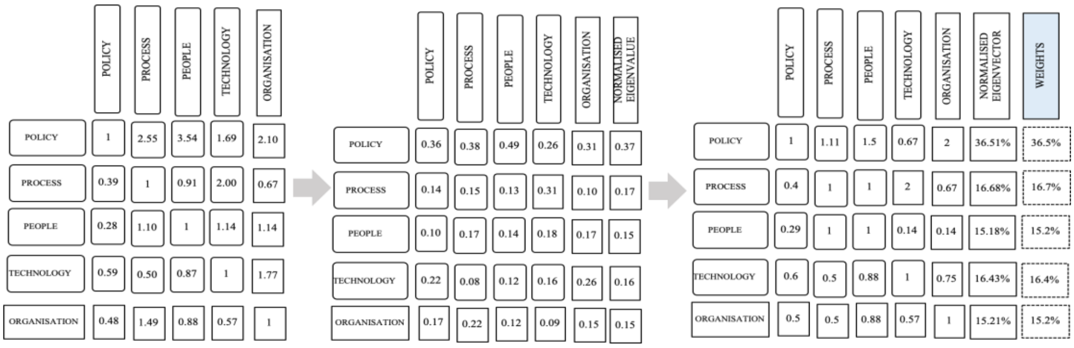

Fig. 5 - Pairwise comparison of main metrics

As illustrated in Figure 5, the first pairwise comparison was made among the criteria parameters influencing the top level in the hierarchy. At this level, main metrics were compared to each other to identify their impact on the BIM performance in the Malaysian construction industry. The 'Policy' was perceived as the most critical metric category, followed by 'Process,' 'Technology,' 'People', and 'Organisation.' The same procedure was applied to each sub-metrics to determine their influence on the main metrics.

Stage 4: Consistency Ratio

Following the formation of the judgmental matrix, the local priorities were established, and the consistency of the outcome was determined. At stage 4, a consistency ratio (CR) was generated to quantify the degree of contradictions in survey respondents' judgements in order to avoid discrepancies (Saaty, 1980). By computing a consistency level for each matrix, any discrepancies that arose during the selection of themes were avoided. The formula was used to compute the CR (Saaty, 1982).

Consistency ratio (CR) = Consistency index (CI)/Random index (RI) *(4)*

where CI = (λ max – n)/ (n – 1), λ max = approximation of the maximum eigenvalue, n = number of elements, and RI = the consistency index of a randomly generated reciprocal matrix within a scale of 1–9. Saaty (1994) set the acceptable consistency index as 0.10. If the consistency ratio is lower than 0.10, then the weight results are valid. However, if the consistency ratio is larger than 0.10, then the results are inconsistent and are thus discarded. For this study, the consistency ratio was calculated automatically by Goepel (2013) AHP Excel Template. Table 4 showed the results of consistency ratio and consensus of the study.

Table 4 - Consistency ratio and consensus

Main Metric	Consistency Ratio (CR)	Decision (CR ≤ 10%)	Consensus	Category
Policy	7.4%	Achieved	72.7%	Moderate
Process	4.5%	Achieved	79.1%	High
Technology	2.8%	Achieved	66.1%	Moderate
People	2.2%	Achieved	79.6%	High
Organisation	1.5%	Achieved	67.4%	Moderate

As seen in Table 4, it was decided that the decisions made for all experts were consistent, given that the CR values of all metrics were lower than 10 % (0.1). Consensus indicates an agreement between respondents, which also assesses the homogeneity of priorities between the participants and is interpreted as the agreement of overlap between the group decision-makers (BPMSG, 2011). The consensus of BIM performance main metrics findings ranged from Moderate to High Consensus. This result indicated the moderation and excellent agreement of judgments among the respondents.

Stage 5: Weighting Score

Finally, in stage 5, the weighting score for each BIM performance was determined. The AHP approach could convert the respondent's subjective judgement into a quantitative analysis, which Goepel AHP Excel Template denoted numerical values. Weighting priorities were determined by comparing two main metrics/sub-metrics on a nine-point scale. By calculating the primary of eigenvector w of matrix A, the weighting of each measure can be calculated (Saaty, 2000):

$$Aw = \lambda max\ w \qquad (5)$$

When vector w was normalised, the vector of the priorities of the assessment themes was generated to the goal. The Goepel (2013) AHP Excel Template could easily calculate the weighting coefficient. Table 5 shows the results of AHP analysis, including the five main metrics and 29 sub-metrics, with their order based on the weightage value.

Table 5 - BIM performance metrics weightage

Main Metric	*Overall Weight (%)*	*Sub-Metric*	*Subordinate Weight (%)*	*Overall Weight (%)*
Policy	**37**	Roles and Responsibility	28	**10**
		Interoperability	19	**7**
		Standard Operating Procedures	17	**6**
		Documenting and Modelling	12	**4**
		Facility Data Management	10	**4**
		Compensation Expectation	10	**4**
		Project Deliverables	4	**2**
Process	**17**	BIM Project Objectives	21	**4**
		BIM Workflow	19	**3**
		Cross-disciplinary Model Coordination	19	**3**
		Clash Analysis Process	14	**2**
		Delivery Method	11	**2**
		Data Exchange	9	**2**
		Management Support	7	**1**
Technology	**16**	Information Accuracy	28	**4**
		Technology Infrastructure Needs	25	**4**
		Spatial and Coordination	22	**3**
		Model Data	10	**2**
		BIM Elements	6	**1**
		Data Security and Saving	5	**1**
		Quality Assurance and Quality Control	4	**1**
People	**15**	Attitudes Towards BIM	44	**7**
		Effective Collaboration	28	**4**
		Experienced Workers	17	**2**
		Skilled Workers	11	**2**
Organisation	**15**	Internal Objectives	46	**7**
		Internal Capability	23	**3**
		Stakeholders	21	**3**
		Research and Development Collaboration Efforts	10	**2**
			Total	**100**

The normalised weights for each metrics were calculate according to theirs perceived contribution to the BIM implementation in an organisation. The total overall weight is 100. 'Policy' was the highest-ranking and the most important metric to evaluate organisational BIM performance in the Malaysian construction industry. However, 'People' and 'Organisation' values held the lowest importance. The weights were similar and shared the importance level, which indicated that the metrics were related to each other. Individuals performed a specific task in order to achieve the organisation objective.

5. Discussion

5.1 Development of the BIM Performance Model for the Malaysian Construction Industry

The results from the AHP effectively assisted in the establishment of the BIM performance model for the Malaysian construction industry as illustrated in Figure 6. According to the findings, this study model includes three critical levels: Performance Scope, Performance Metrics, and Performance Level Classifications. A detailed discussion of the developed model is delineated as follows.

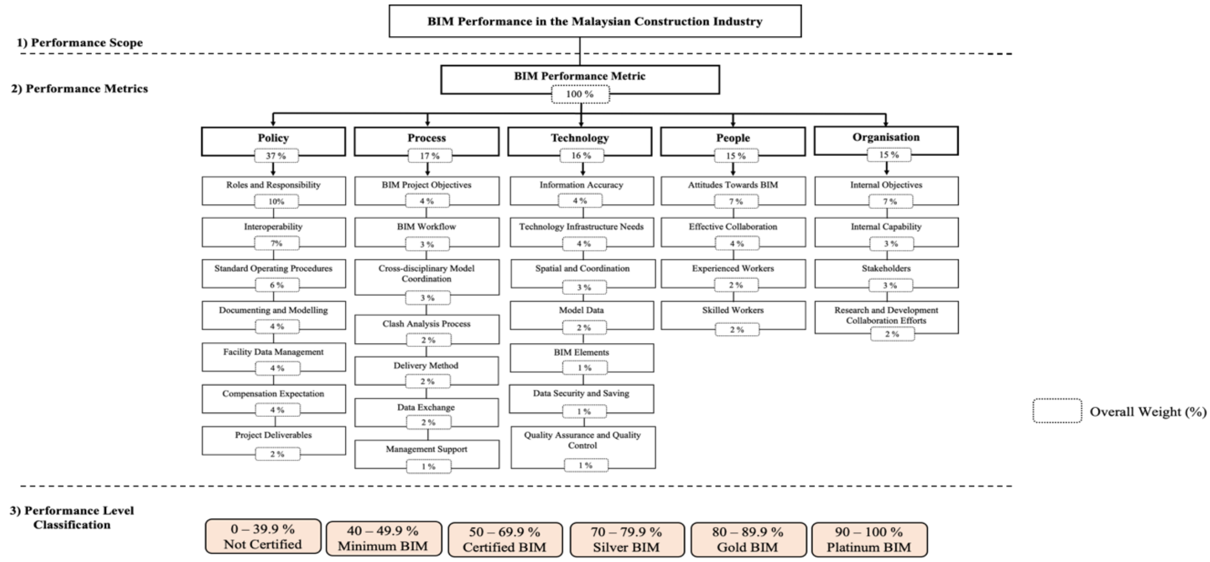

Fig. 6 - BIM performance model for the Malaysian construction industry

Level 1 - Performance Scope

The first component of the BIM performance model is the performance scope. Succar (2013) said that BIM performance may be measured using three scopes; individual, organisation and project performance. The model was developed to only evaluate BIM performance in an organisation in the Malaysian construction industry due to the limited project implementation of BIM as a whole and the lack of individual experts in BIM. Understanding the evaluation scope could serve as organisation guidance to select the metrics for the evaluation process. In other countries, there are thirteen BIM performance models have been identified to evaluate BIM performance in an organisation. For example, BIM Interactive Capability Maturity Model (I-CMM), UK BIM Maturity Model, BIM Proficiency Matrix, BIM Maturity Matrix, BIM QuickScan, CPIx-BIM Assessment Form, VDC Scorecard, bimSCORE, Organisation BIM Assessment Profile, BIM Cloud Score (BIMCS), Owner BIM Competency Assessment Tool, Multifunctional BIM Maturity Model, and BIM Capability Assessment Reference Model (BIM-CAREM).

Level 2 - Performance Metrics

As shown in Figure 2, the performance metrics in the BIM performance model are divided into two levels; main metrics and sub-metrics. The first level of BIM performance metrics are the main metrics (Process, People, Policy, Technology, Organisation); the second level was further divided into twenty-nine sub-metrics. The studies of Giel and Issa (2013) and Succar (2009) were also classified into these five main metrics.

In this study, most of the BIM performance metrics in this model are adopted from the Multifunctional BIM Maturity Model. This model contains three main metrics: technology, process, and policy. The technology comprises seven sub-metrics: information accuracy, model data, quality assurance and control, data security and saving, technology infrastructure needs, BIM elements, and spatial & coordination. Process metric contains seven sub-metrics: clash analysis process, data exchange, BIM workflow, cross-disciplinary model coordination, delivery method, BIM project objective, and management support. The policy includes seven sub-metrics: interoperability, project deliverables, documenting and modeling standards, standard operating procedures, roles and responsibilities, compensation expectations, and facility data management. All the performance metrics are weighted equally to calculate the overall performance score (Liang *et al*., 2016).

In contrast, this study weighted the performance metrics based on the important level. The first level of BIM performance metrics (Main Metric) showed the Policy is one of the most important metrics to evaluate BIM performance in an organisation. It was proven through AHP that this main metric was ranked first in importance. The policy was developed as a contract between clients and the BIM project team. This condition supported the effectiveness of collaborative work between the project parties. It was also a guideline for the organisation to implement BIM' Technology' and 'Process' in their project. Process (17%) and Technology (16%) were recorded as the essential metrics in implementing BIM in an organisation. The importance of weight was almost the same due to their influence on each other. The weight of 'People' and 'Organisation' amounted to 15%, which indicated the relationship between people and organisation. The organisation presented the relationships between people who work together towards a goal. Notably, an organisation would not be formed without its people. Similarly, the organisation is strongly influenced by the people who form a part of it.

In the second level of BIM performance metrics, A total of 29 sub-metrics were selected to evaluate BIM performance in an organisation. The highest weightage of the sub-metric was 'Role and Responsibility (10%). To correctly manage a BIM project, 'Roles and Responsibility' standardisation is required. It is vital to ensure that all the workers fully know their responsibility. Latiffi *et al*. (2016) found that the role and responsibilities of construction players in construction projects using BIM were different from those in conventional projects. Wu *et al*. (2017) agreed that duty arrangements are universally important. In evaluating the 'Process' metric, 'BIM Project Objectives' (4%) was recorded with the highest score among the sub-metrics. Objectives are specific tasks or steps that guide the organisation toward its goals (Messner & Kreider, 2013). For smooth BIM application within an organisation, strict consideration should be placed on the organisation's long-term goals and requirements (Enegbuma *et al*., 2014). The other sub-metrics, namely 'BIM Workflow' and 'Cross-Disciplinary Model Coordination', also play the most crucial role in ensuring that 'Process' achieves the maximum score. 'Information Accuracy' was recorded with the highest weightage to evaluate the 'Technology' category. The ground truth has been implemented, indicating that polygons are located and used to compute space and volume and identify the quantified areas. Therefore, it is included as a part of the minimum BIM (NIBS, 2015). Information accuracy defines the closeness of the information received to the truth (Chen *et al*., 2014). The lack of information about the project details would lead to a critical failure and high initial investment cost of the BIM project.

Level 3 - Performance Level Classification

The third component is the BIM performance level classification. The BIM implementation performance grade in an organisation was determined by the level classification. The level categorization was determined by the final score from the performance review of all BIM performance metrics. Since the Malaysian construction industry preferred classification as the GBI and MyCREST ratings, this model was adopted from the BIM Interactive Capability Maturity Model (I-CMM) level classification. The BIM level classification of the model was further confirmed through model validation. The BIM performance in an organisation is classified as Not Certified, Minimum BIM, Certified BIM, Silver BIM, Gold BIM, and Platinum BIM. The highest level of BIM performance is indicated as Platinum BIM, which shows the organisation's outstanding performance. In addition, it proved that the organisation is competent and experienced in implementing BIM. Meanwhile, the lowest BIM performance level is Not Certified, which indicates the organisation has no BIM experience and cannot perform in BIM.

6. Conclusion

In conclusion, the BIM performance model provides a more comprehensive evaluation technique that takes into account the Malaysian building industry scenario. The crucial finding for the suggested BIM performance model in the Malaysian construction industry was the BIM evaluation scope, BIM performance metrics and the value of weighting. Significantly, there were differences with the existing BIM performance models. The BIM performance models provide essential components of the BIM performance evaluation based on Malaysia's context. In summary, the proposed BIM performance model suits the context of the Malaysian construction industry. However, the study could be expanded in future works to investigate the elements of BIM performance evaluation based on individual competency and project performance. Provided that the BIM performance model was developed generally, the model requires customisation in terms of organisation types from the viewpoint of contractors, developers, and consultants.

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