Civil Engineering and Architecture 10(4): 1538-1546, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100423

Building Information Modelling (BIM) Performance Metrics Using Analytic Hierarchy Process (AHP)

Rolyselra Orbintang Robin[1], Mohd Yamani Yahya[1,*], Azlina Md Yassin[2], Haidaliza Masram[2]

[1]Department of Construction Technology Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia
[2]Department of Real Estate Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia (UTHM), Johor Malaysia

Received October 19, 2021; Revised January 1, 2022; Accepted January 25, 2022

Cite This Paper in the following Citation Styles

(a): *[1] Rolyselra Orbintang Robin, Mohd Yamani Yahya, Azlina Md Yassin, Haidaliza Masram , "Building Information Modelling (BIM) Performance Metrics Using Analytic Hierarchy Process (AHP)," Civil Engineering and Architecture, Vol. 10, No. 4, pp. 1538-1546, 2022. DOI: 10.13189/cea.2022.100423.*

(b): *Rolyselra Orbintang Robin, Mohd Yamani Yahya, Azlina Md Yassin, Haidaliza Masram (2022). Building Information Modelling (BIM) Performance Metrics Using Analytic Hierarchy Process (AHP). Civil Engineering and Architecture, 10(4), 1538-1546. DOI: 10.13189/cea.2022.100423.*

Abstract An organization must evaluate its internal ability to optimize the benefits of BIM. Hence, it is important to provide a set of numerical weights for each performance metric before starting the evaluation. Hence, this study applies the Analytical Hierarchy Process (AHP) technique to assign weights for the organizational BIM performance evaluation. The AHP survey was collected using self-completion method and received feedback from twenty (20) respondents. Findings from AHP Survey were analyzed using AHP Excel Template. This analysis has set a weighting value for each metric. As a result of using the AHP technique, the consistency value (CR) of all metrics determined was less than 0.1, which indicates that the experts' decisions were consistent. In addition, the value of consensus also exceeds 50 %, which confirms that the agreement on the value of metric weights among the experts is acceptable. Subsequently, the AHP had successfully assigned the weightage to all BIM performance metrics, with five (5) Main Metrics as the most critical metrics; Policy (37%), Process (17%), Technology (16%), People (15%), and Organization (15%).

Keywords Building Information Modelling (BIM) Performance, Analytic Hierarchy Process (AHP)

1. Introduction

The failure to understand the BIM performance evaluation areas causes the organization to maximize the benefits of BIM. The evaluation areas are the basis for the organization to improve its BIM processes and deliverables. Apart from that, the lack of a way to systematically scale evaluation to assess the BIM application in an organization will make tracking their weakness and possible risks challenging. They will fail to identify gaps in the BIM application, including the organization's resources and how these gaps can be addressed. If these matters happen, the organization is unable to improve and miss growth opportunities.

Consequently, it is necessary to develop consistent BIM performance evaluation to guide the organization to understand the performance and level of performance that suits their organizational needs; therefore enabling to utilize and build BIM capabilities. Various BIM performance models are being developed to assist businesses in achieving various BIM evaluation goals in the construction sector. They differ in terms of applicability and evaluation intent (Wu et al., 2017). Some demand a third-party assessor (with fee), some lack guidelines on using them, while others need a couple of hours to complete. Therefore, an expanded BIM performance model for the evaluation is preferred.

In order to develop a performance model, selecting suitable and conducive BIM performance evaluation metrics is a prerequisite to ensure the effectiveness of the evaluation. By knowing the relevant metrics, an organization will be alert and precise about the organization's internal system and resources capability. After identifying the performance metrics in a BIM performance evaluation, it is crucial to compute the overall weightage for each performance metric before starting the evaluation. This study was employed the AHP technique to assign weightage for each metric.

Through pairwise comparisons, the AHP technique enabled the experts to evaluate the weightings with better consistency. It is a theory of measurement based on pairwise comparisons that depends on expert judgment to establish priority scales (Alexander, 2012; Bunruamkaew, 2012; Saaty, 2008). Because AHP depends on expert judgment, it has been widely accepted as a decision-making tool in the built environment domains (Poveda & Lipsett, 2011; Ali & Al, 2008; Chen *et al*., 2006). Therefore, the application of AHP for this study is vital to assign the weight of each metric. Furthermore, the technique produces no biased results because the weighted judgment is based on the experts' conclusion. Furthermore, the AHP approach enables for the internal consistency of the respondents' results to be evaluated.

2. Literature Review

2.1. Building Information Modelling (BIM) in the Construction Industry

Azhar *et al*. (2008) defined BIM as the process of developing and utilizing a computer-generated model to replicate a facility's planning, design, building, and operation. He defined BIM, like Hardin (2009), as a process of making significant changes in the workflow and project delivery process by using three-dimensional (3D) intelligent models. BIM is a modeling technology that allows you to create, communicate, and analyze building models (Eastman *et al*., 2011).

Recent software developments, as well as the performance of current microprocessors, have made BIM technologies conceivable (Abanda *et al*., 2017), and they are based on a few basic and straightforward principles. These factors improve the accuracy of the project, reliability, team efficiency, and construction quality, benefiting all parties involved (Bongiorno *et al*., 2019). The concept of BIM evolved from the idea of 3D project modeling. It later grew to include 4D modeling (construction processing and scheduling), 5D modeling (cost prediction), 6D modeling (sustainability), 7D modeling (facility management), and nD modeling (Mohanta & Das, 2017). It highlights how BIM may be used to integrate the various stages of a production project's lifetime (Jung & Joo, 2011). In recent years, the number of dimensions used to depict building has increased from the typical three-dimensional (for spatial representation) to n-dimensions (Lee *et al*., 2019). Bongiorno *et al*. (2019) consider BIM as the 8-Dimension (Figure 1).

2.2. BIM Performance

According to Succar (2016), BIM performance is a broad term that encompasses a wide range of metrics. It covers the abilities and deliverables that individuals, organizations, projects, and teams can expect or achieve when using BIM tools and workflows. The metrics that affect BIM performance are divided into two stages. The Main Metrics are the first stage of BIM performance, followed by the Sub-Metrics. The Main Metrics are a small number of issues that are critical to the success of BIM implementation. These metrics identification can also aid in the benchmarking of BIM performance in specialized categories. Meanwhile, the Sub-Metrics that evolved in BIM performance are listed under each Main Metrics.

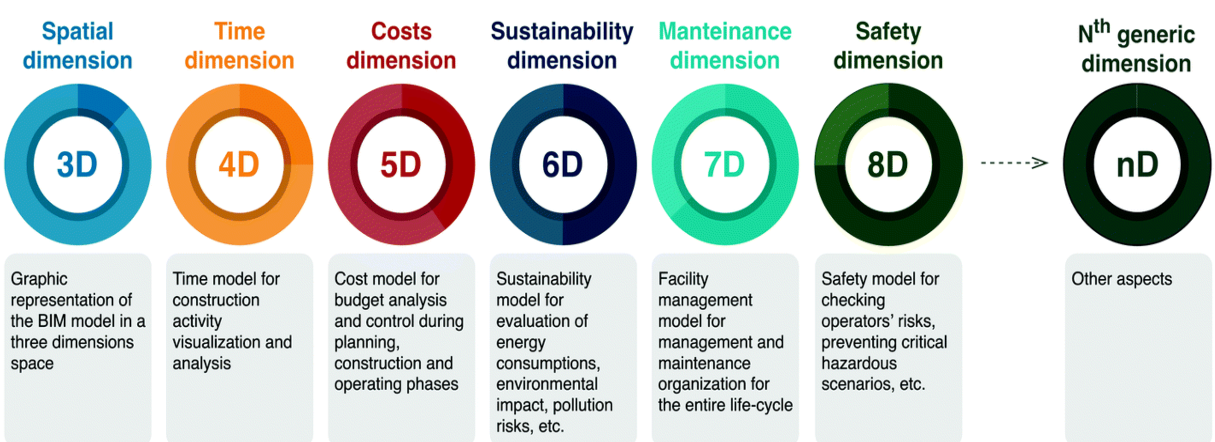

Figure 1. BIM Dimensions

Table 1. Main Metrics and Sub-Metrics of the BIM Performance

No	Main Metric	Sub-Metric	Authors
1	Process	Clash Analysis Process	NIBS (2012)
		BIM Project Objective	Messner & Kreider (2013)
		Data Exchange	AEKC UK (2010)
		Cross-disciplinary model coordination	Seng (2012)
		BIM Workflow	AEKC UK (2010)
		Delivery Method	NIBS (2012)
2	People	Management Support	Messner & Kreider (2013)
		Attitude Towards BIM	Sebastian & Van Berlo (2010)
		Experience Workers	Singapore Building Construction Authority (2013)
		Skills Workers	Arayici *et al*. (2011)
		Personal Traits	Won *et al*. (2013)
3	Policy	Standard Operating Procedures (SOP)	Won *et al*. (2013), Chen *et al*. (2014)
		Document and Modelling Standard	Chen *et al*. (2014)
		Interoperability	NIBS (2012)
		Roles and Responsibility	Messner & Kreider (2013)
		BIM and Facility Data Requirement	Messner & Kreider (2013)
		Project Deliverables	PSU (2012)
		Compensation Expectation	Seng (2012)
4	Technology	Spatial and Coordination	AEKC UK (2010)
		Technology Infrastructure Needs	Messner & Kreider (2013)
		Model Data	HKIBIM (2015)
		Data Security and Saving	Seng (2012)
		Information Accuracy	NIBS (2012), Chen *et al*. (2014)
		Quality Assurance and Quality Control	Seng (2012)
		BIM Elements	Messner & Kreider (2013)
5	Organization	Internal Capability	McGraw-Hill Construction (2009)
		Internal Objectives	McGraw-Hill Construction (2009)
		Research and Development Collaboration Efforts	Osman *et al*.,(2015); Ahn *et al*.,(2016)
		Stakeholders	McGraw-Hill Construction (2009), Won *et al*. (2013)

Robin & Yahya (2018) stated that BIM performance could be evaluated based on five (5) metrics; Policy, Process, Technology, People, and Organization. The Policy may consist of a set of written or unwritten contractual contracts that supersede prior agreements about coordination and conflict resolution, model ownership, and model management (AEC UK 2010, 2012). A Process can be defined as the procedure of generating building data and information for design, construction, and operation projects (McGraw Hill Construction, 2009). Technology is used in BIM to refer to a collection of techniques, skills, procedures, and processes. It is mostly composed of BIM-related software and hardware (Autodesk Revit, Bentley, and Tekla) (computers and displayers). Individuals with expertise in using technology to create BIM models are known as People. The Organization is a group of organised and structured people to implement BIM in the project. The Main Metrics and Sub-Metrics used in this study are summarised in Table 1.

3. Methods

The data was collected using Analytical Hierarchy Process (AHP) survey. The respondents were BIM professionals from both public and private organizations, which was appropriate given that the AHP technique relies on the experts' judgment to regulate input throughout the process. The purposive sampling was selected respondents based on three criteria; their position in the organization, years of BIM experience, and the number of BIM projects. Due to the lack of information regarding BIM experts in the Malaysian construction industry, the researcher has requested the information of individuals or groups involved in BIM projects from the Public Works Department Malaysia (PWD), MyBIM Centre, and interview respondents. Consequently, the questionnaire survey was distributed to thirty-five (35) BIM practitioners across Malaysia wide. Nevertheless, only twenty (20) respondents were returned the questionnaires survey to the researcher. The total number of responses is still within acceptable limits. According to prior studies, the AHP survey requires a minimum sample size of four participants (Akadiri et al., 2013; Chou et al., 2013; Pan et al., 2012). There have only been a few studies that have used sample sizes bigger than 30 people (El-Sayegh, 2009; Ali & Al Nsairat, 2009). The extant literature on AHP applications in construction indicates no strict requirement on the minimum sample size for AHP analysis. Thus, twenty (20) respondents are moderate and adequate for the AHP survey in this study.

The twenty (20) AHP survey respondents had fitted the three (3) criteria of the respondents' selection. The first criterion to choose the experts is their position in the organization—selecting the respondents involved directly in the BIM processes. For example, the respondents from the private sector consisted of a BIM manager, coordinator, and modeler. While from the public sector from the BIM unit Public Works Department Malaysia (PWD), the second criteria are the years of the respondent's experience dealing with BIM. In this study, nineteen (19) respondents experience in BIM more than five years except one who experiences below than five years. This respondent is still labelled as an expert because he/she was involved in three BIM projects. Following the third criteria, the respondent involved in three and more BIM projects was also categorized as an expert. The last criteria are the numbers of BIM projects that the respondents are involved. This study classified the respondents who already participated in three and more BIM projects as eligible to join the AHP survey. All of the respondents comply with the third criteria.

The AHP survey was collected by self-completion; email questionnaires, WhatsApp, and SurveyMonkey.com were used to solicit feedback from respondents. Apart from that, the researcher collected data using an AHP form. The primary phases in developing an AHP framework are pairwise comparisons of Main Metrics and Sub-Metrics, normalized weights for Main Metrics and Sub-Metrics, calculation of the Consistency Ratio (CR), and calculation of the Consensus.

Step 1: Pairwise Comparison of Main Metrics and Sub-Metrics

The first step was collecting the data by comparing all metrics on each hierarchy level. To attain this aim, this study designed a questionnaire based on Saaty's comparative scale. The scale ranged from one to nine, which is an adequate range for pairwise comparisons in general. This scale quantifies each element's supremacy over the other elements in the hierarchy. The Saaty scale's drawback is that it can only compare one set of criteria at a time. Table 2 illustrates Saaty's scale of relative importance.

Table 2. Scale of relative importance (Adapted from Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another. Its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

One can develop a performance comparison for each selection criterion using the scale of relative relevance. This step compares each measure against the others based on the various selection criteria. The final matrix of comparisons is referred to as the criteria judgment matrix. It is used to indicate the relative relevance of individual criteria as provided by the user. Figure 2 shows of comparison between two Main Metrics by the respondent—for example, a comparison between Policy and Process. Respondent chose Policy more important than Process with scale 3 (Moderate Importance).

Main Metric	← Weight →																	Main Metric
Policy	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Process
Policy	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	People
Policy	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Technology
Policy	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organization
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 ☐	Technology
Process	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organization
People	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Technology
People	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organization
Technology	9 ☐	8 ☐	7 ☐	6 ☐	5 ☐	4 ☐	3 ☐	2 ☐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	Organization

Figure 2. Example of AHP Questionnaire

Table 3. Third Iteration

	Policy	Process	People	Technology	Organization	Normalized principal eigenvector
Policy	1	1.11	1.5	0.67	2	36.51%
Process	0.4	1	1	2	0.67	16.68%
People	0.29	1	1	0.14	0.14	15.18%
Technology	0.6	0.5	0.88	1	0.75	16.43%
Organization	0.5	0.5	0.88	0.57	1	15.21%

Step 2: Normalized Weight of Main Metrics and Sub-Metrics

The second step was to evaluate the comparative data using a Goepel-developed AHP Excel template (2013). The template is compatible with Windows operating systems and Microsoft Excel 2010. The workbook contains twenty input worksheets for pairwise comparisons, as well as a summary of all judgements, the display of results, reference tables and a sheet for solving the eigenvalue problem when using the Eigenvector method (EVM). Table 3 shows the outcome from the analysis (Normalized Weight of Main Metrics and Sub-Metrics).

Step 3: Calculate Consistency Ratio (CR)

The third step was to calculate the Consistency Ratio (CR). Based on Saaty's previous findings (1990), if the CR is greater than 10%, the results are inconclusive. As a result, values should be adjusted until CR is verified.

Step 4: Check Consensus

The last step was to check the consensus or an agreement between respondents. It assesses the homogeneity of priorities between the respondents and is interpreted as the group decision-makers agreement (BPMSG, 2011). The values below 50% indicate no consensus within the group and high diversity of judgements. At the same time, the value from 80% to 90% indicates an excellent agreement of judgements from the respondents. Table 4 shows the consensus categories.

Table 4. Consensus Categories (BPMSG, 2011)

Categories	Percentage
Very high consensus	Above 85%
High consensus	75% to 84%
Moderate consensus	65% to 74%
Low consensus	50% to 64%
Very low	Below 50%

4. Results and Discussion

The purpose of this study is to apply a weighting to BIM performance measures. The weighting of the Main Metrics is shown in Table 5. It demonstrates that the internal consistency ratio (CR) is 6% (0.06), when the CR in AHP must be less than 0.1 (10%). (Saaty, 1990). As a result, the data is reliable and consistent.

Table 6 describes the findings from the AHP survey analysis that put all the five (5) Main Metrics and twenty-nine Sub-Metrics on their ranking order based on weightage value.

Table 5. BIM Performance Main Metrics

Main Metric	Weightage (%)
Policy	37
Process	17
Technology	16
People	15
Organization	15
Total	100
Consensus	69.8%
Category	*Moderate Consensus*
Consistency Ratio	6%

Table 6. The Weightage of the Main Metrics and Sub-Metrics

Main Metric	Local Weight (%)	Sub-Metric	Local Weight (%)	Global 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
		Personal Traits	28	4
		Experience Workers	17	2
		Skills Workers	11	2
Organization	15	Internal Objectives	46	7
		Internal Capability	23	3
		Stakeholders	21	3
		Research and Development Collaboration Efforts	10	2
Total	100			100

In order to determine the weight of Main-Metrics and Sub-Metrics, the Local Weight (LW) coefficients of each metrics were obtained by comparing all metrics in pairs. Global weight (GW) was calculated by multiplying the LW of each metric.

As shown in Table 7, it was determined that all expert conclusions were consistent because the CR values for all metrics were less than 10%. (0.1). At the same time, the consensus of Main Metrics findings ranged from Moderate to High Consensus. It shows moderation and excellent agreement of judgments among the respondents. The findings are at an acceptable level.

Figure 3 shows the main metrics and sub-metrics arranged according to ranking based on the importance level as tabled in Table 6. With a weightage of 37%, policy showed the highest score and was the most important metric influencing BIM performance. Any failure to comply with the sub-metrics in the Policy category will directly and greatly affect the overall performance of the BIM. The Process (17%) came in as the second importance, followed by Technology (16%). These two main metrics have very similar weightage. Finally, People and Organization showed the lowest weight at 15%. These metrics will be used to develop BIM performance evaluation model.

5. Conclusions

Performance metrics are indicators of an organization's success with BIM implementation. Furthermore, it is critical for an organization's BIM objectives to be met. The goal of this research is to use the Analytical Hierarchy Process to develop BIM performance metrics (AHP). In this regard, the weightages of the five (5) Main Metrics and twenty-nine (29) Sub-Metrics were calculated. In Stage 1, the Policy category has the highest score (37%). Process and technology are the next two items on the list. People and Organization have the lowest scores. Simultaneously, Sub-Metrics from Policy (Roles and Responsibility) score the highest in Stage 2.

Table 7. Consistency Ratio and Consensus to AHP Analysis

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

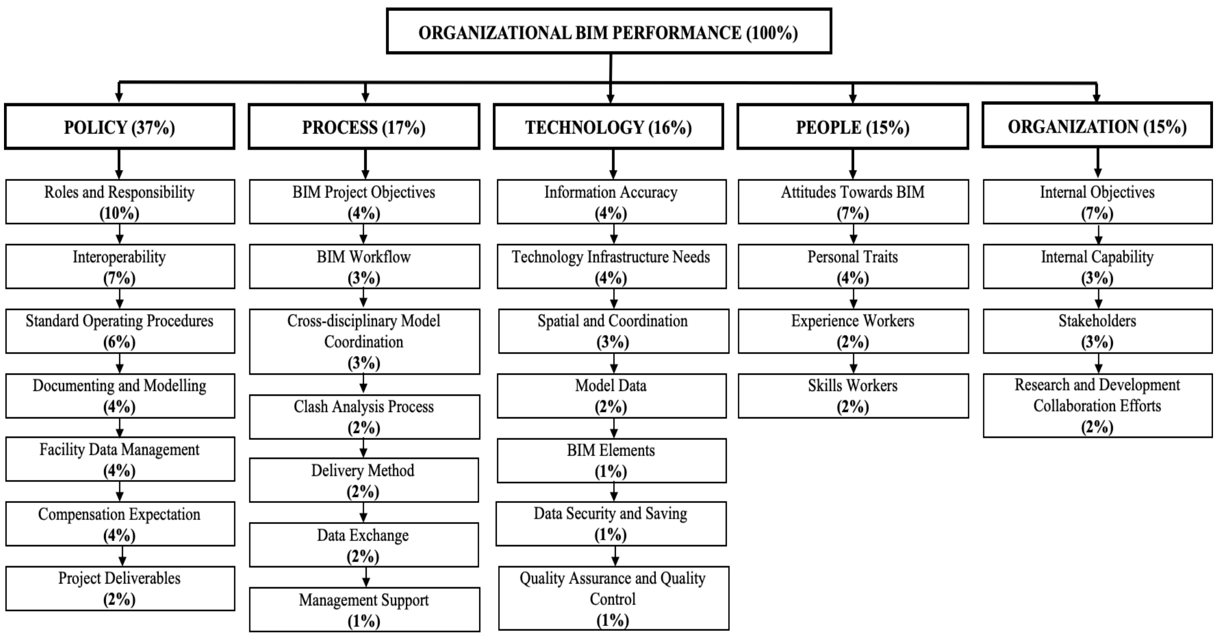

Figure 3. Hierarchy of BIM Performance Metrics Weightage

Acknowledgments

The authors like to express their gratitude to the Malaysian Ministry of Education (MOE) and Universiti Tun Hussein Onn Malaysia (UTHM) as well as the participants, whose willingness to share all information for this paper is appreciated.

REFERENCES

[1] Abanda, F. H., Kamsu-Foguem, B., & Tah, J. H. M (2017). BIM – New Rules of Measurement Ontology for Construction Cost Estimation. *Engineering Science and Technology, and International Journal*, 20(2), Pp. 443–459.

[2] AEC UK. (2010). BIM Standard for Autodesk Revit—A Workable Implementation of the AEC (Uk) BIM Standard for the Architectural, Engineering and Construction Industry in the UK

[3] AEC UK. (2012). BIM Protocol—Implementing UK BIM Standards for the Architectural, Engineering and Construction Industry.

[4] Ahn, Y. H., Kwak, Y. H., & Suk, S. J. (2016). Contractors' Transformation Strategies for Adopting Building Information Modeling. *Journal of Management in Engineering*, 32(1), 1–13.

[5] Akadiri, P. O., Olomolaiye, P. O., & Chinyio, E. A. (2013). Multi-Criteria Evaluation Model for the Selection of Sustainable Materials for Building Projects. *Automation in Construction*, 30, 113-125.

[6] Alexander, M. (2012). Decision-Making Using the Analytic Hierarchy Process (AHP) and SAS/IML.

[7] Ali, H. H., & Al Nsairat, S. F. (2009). Developing A Green Building Assessment Tool for Developing Countries–Case of Jordan. *Building and Environment*, 44(5), 1053-1064.

[8] Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'reilly, K. J. S. S. (2011). BIM Adoption and Implementation for Architectural Practices. *Structural Survey*.

[9] Azhar, A., Hein, M., & Sketo, B (2008). Building Information Modeling (BIM): Benefits, Risks and Challenges. Proc., 44th Associated Schools of Construction National Conference, Auburn, Al.

[10] Bongiorno N., Bosurgi G., Carbone F., Pellegrino O., & Sollazzo G. (2019). Potentialities of A Highway Alignment Optimization Method In An I-BIM Environment. Periodica Polytechnica Civil Engineering, 63(2), Pp. 352–361, 2019.

[11] Business Performance Management Singapore (BPMSG) (2011). Concepts, Methods and Tools to Manage Business Performance.

[12] Bunruamkaew, K., (2012). How to Do AHP Analysis In Excel. In: Division of Spatial Information Science. University Of Tsukuba.

[13] Chen, Z., Clements-Croome, D., Hong, J., Li, H., & Xu, Q. (2006). A Multicriteria Lifespan Energy Efficiency Approach to Intelligent Building Assessment. Energy Build.

[14] Chen, Y., Dib, H., & Cox, R. F. (2014). A Measurement Model of Building Information Modelling Maturity. *Construction Innovation*, 14(2), 186–209.

[15] Chou, J. S., Pham, A. D., & Wang, H. (2013). Bidding Strategy to Support Decision-Making by Integrating Fuzzy AHP and Regression-Based Simulation. *Automation in Construction*, 35, 517-527.

[16] Eastman, C. M., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM Handbook*: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors. John Wiley & Sons.

[17] El ‐ Sayegh, S. M. (2009). Multi ‐ Criteria Decision Support Model for Selecting the Appropriate Construction Management at Risk Firm. *Construction Management and Economics*, 27(4), 385-398.

[18] Goepel (2013). Implementing the Analytic Hierarchy Process as A Standard Method for Multi-Criteria Decision Making in Corporate Enterprises A New AHP Excel Template with Multiple Inputs. In: Proceedings of The International Symposium on the Analytic Hierarchy Process, Kuala Lumpur, Malaysia; P. 110

[19] Jung, Y., & Joo, M. (2011). Building Information Modelling (BIM) Framework for Practical Implementation. *Automation in Construction*, 20(2), 126-133.

[20] Lee, A., Wu, S., Marshall-Pointing, A. J., Aouad, G., Cooper, R., Tah, J. H. M., Abbott, C., & Barrett, P. S. (2005). "Nd Modelling Road Map: A Vision for Nd-Enabled Construction", University Of Salford, Manchester, Great Britain.

[21] Mcgraw Hill Construction. (2009). Smartmarket Report-The Business Value of BIM: Getting Building Information Modeling to the Bottom Line. New York.

[22] Mohanta, A., & Das, S. (2017). BIM as Facilities Management Tool A Brief Review.

[23] National Institute of Building Sciences (NIBS)(2012). "United States National Building Information Modeling Standard: Version 2." Washington, Dc.

[24] Osman, J., Mazlina, S., Khuzzan, S., & Razaksapian, A. (2015). Building Information Modelling : Proposed Adoption Model for Quantity Surveying Firms. Proceeding of Ic-Its 2015, *International Conference On Information Technology & Society*, (June), 151–165.

[25] Pan, W., Dainty, A. R., & Gibb, A. G. (2012). Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction. *Journal of Construction Engineering and Management*, 138(11), 1239-1250.

[26] Poveda, C. A., & Lipsett, M. G. (2011). A Review of Sustainability Assessment and Sustainability/Environment al Rating Systems and Credit Weighting Tools. *Journal of Sustainable Development*, 4(6), 36-55.

[27] Saaty, T. L. (1980). The Analytic Hierarchy Process, Planning, Priority Setting, Resource Allocation. Mc Graw-Hill, Ny 1980.

[28] Saaty, T. L. (1990). How to Make A Decision: The Analytic Hierarchy Process. European *Journal of Operational Research*, 48(1), 9-26.

[29] Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, 1(1), 83-98.

[30] Sebastian, R., & van Berlo, L. (2010). Tool for Benchmarking BIM Performance of Design, Engineering and Construction Firms in the Netherlands. *Architectural Engineering and Design Management*, 6(4), 254-263.

[31] Seng, L. C. (2012). Singapore BIM Guide.

[32] Singapore Building Construction Authority (2013). Singapore BIM Guide—Version 2. Singapore: Building and Construction Authority Singapore.

[33] Succar, B. (2009). Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders. *Automation in Construction*, 18(3), 357–375.

[34] Succar, B. (2016). BIM Performance Assessment. Emirates BIM User Group. Dubai.

[35] Won, J., Lee, G., Dossick, C., & Messner, J. (2013). Where to Focus for Successful Adoption of Building Information Modelling Within Organization. *Journal of Construction Engineering and Management*, 139(11), 04013014.

[36] Wu, C., Xu, B., Mao, C., & Li, X. (2017). Overview of BIM Maturity Measurement Tools. *Journal of Information Technology in Construction (ITCon)*, *22*(3), 34-62.