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TECHNOLOGY ACCEPTANCE MODEL FOR BUILDING INFORMATION MODELLING BASED VIRTUAL REALITY (BIM-VR) IN COST ESTIMATION

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SUMMARY: The accuracy of cost estimation during the preliminary stage of a construction project is imperative. However, owing to limited accessibility of information, the level of accuracy required at this stage of a project is extremely difficult to be attained. In like manner, the risks of budget shortages or cost overruns are likely to surge exponentially due to an incompetent or a lackadaisical approach towards life-cycle costing. Hence, this study proposes BIM-based VR as a preliminary estimating solution which is purported to nip the aforementioned issues in the bud. BIM-VR enables BQ to be updated automatically as stakeholders performs modifications on-the-go, allowing speedy and highly accurate design adjustments throughout the project. On this front, the Technology Acceptance Model (TAM) was adopted to determine the acceptance level of BIM-based VR technology in Malaysia. Data was acquired via a questionnaire survey, of which 92 out of 180 distributions were accepted for analysis, accounting to a respectable response rate of 51%. Consequentially, Principal Component Analysis result revealed that 'Saving Cost and Resources' is the most significant factor for BIM acceptance. Conversely, 'Presence of Skill Gap' was found to be the biggest stumbling block for BIM-based VR in cost estimation. Relationship analysis from the TAM also unveiled that the challenges of BIM-based VR did not produce mediating effect towards attitude and intention to use. This implies that the intention of construction professionals to adopt the technology wasn't impeded by its challenges. Significantly, this study served as a benchmark in uncovering new possibilities of BIM and VR in project cost management, where the reliability and accuracy of conventional procurement can be enhanced with technology, particularly in BQ documentation, to fulfill the rising expectations of construction stakeholders across the globe.

KEYWORDS*: Cost Estimation, Building Information Modelling, Virtual Reality, Technology Acceptance Model*

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1. INTRODUCTION

Poor cost estimation has always been a critical issue in the construction industry today due to the highly complex nature of projects. The high level of dynamism and complexity has ultimately contributed to the escalated uncertainty in the construction projects. The high level of uncertainty would eventually drive the projects towards more problems such as cost overruns (Aljohani, Ahiaga-Dagbui. Dominic and Moore, 2017). Cost overrun is one of the most common concerns in construction projects (Memon, Rahman and Azis, 2011). This trend is especially pronounced in developing countries, where cost overruns can potentially surpass 100% of the initial budget (Memon, Rahman and Azis, 2011). The most common instances would be the oversights and misunderstandings that happened only during the construction stage, resulting in rework and additional costs. Next, B/Q is also very prone to human error because the tasks are generated manually. Estimators regularly make obsolete errors such as omissions, double-counting, and misusing outdated drawings. Hence, BIM is introduced to streamline the collaboration between construction professionals and provide a reliable and efficient quantity take-off.

Building Information Modelling (BIM) is a sophisticated digital information management system that can help facilitate projects with processes and information distribution. In terms of cost estimation, BIM can help to reduce significant amount of time and cost of estimators. This can be done as the construction materials, quantities and properties can be easily retrieved from BIM. Then, the information is linked to the cost estimation database to estimate the overall project cost (Ramaji *et al.*, 2018). Despite providing many benefits in doing cost estimation, BIM alone does not offer immersive visualization. With that, it resulted in problems like oversight and misunderstanding of elements when performing quantity take-off (Davidson *et al.*, 2019). Hence, VR is proposed to offer immersive visualization in a 1:1 scale.

Virtual Reality (VR) is incorporated into BIM workflow to mainly assist in immersive visualization and provide alternative solutions in the early stage and eliminate construction discrepancies. VR can overcome misunderstandings and oversight issues by providing a realistic representation of elements such as interior finishes, carpentry, and ironmongery, which clients often find hard to visualize. VR enables clients to recommend modifications to the design before being quantified into the final B/Q. This enhances the document's accuracy by precisely reflecting the client's expectations in a project. Next, it would also eliminate last-minute changes, which could lead to additional expenses (Ahmed, 2020).

Numerous models can be utilized to develop BIM-based VR solutions, and the adoption rate has been increasing recently as more construction professionals are beginning to accept the new change. Most of recent BIM-based VR studies are mainly related to a particular application level; however, only a handful of studies were carried out on the issues related to the successful implementation of BIM-based VR integration. Little research has been done to investigate how the construction sector accepts and implements BIM-based VR into its operations. Hence, this study aims to fill the missing gap by building a TAM for BIM-based VR in cost estimation. The findings are significant as future researchers could use them to identify future directions and discover research possibilities. Next, the discovered factors such as PEU and PU will benefit the construction industry while adopting or developing the new BIM-based VR platform. This study aims at enhancing the cost estimation through the usage of BIM-based VR in construction industry. The objectives of this study are to identify the potential benefits of BIM-based cost estimation, examine the challenges of BIM-based VR in cost estimation and to develop a TAM for BIM-based VR integration in cost estimation.

2. LITERATURE REVIEW

2.1 Conventional Cost Estimation

The goal of cost estimation is to evaluate a project's feasibility and provide a comprehensive budgeting plan. Generally, project cost estimation can be categorized into two categories: preliminary estimates and detailed estimates (Lee *et al.*, 2020). The preliminary estimate is performed during the initial phase, where the design information and time are limited to generate a precise estimate. In contrast, a detailed estimate is performed between the execution and closure phase, which naturally results in more accurate forecasts as the drawings have all been finalized. Hence, this study suggests focusing on implementing BIM-based VR from the initial phase of a construction project to spot and rectify all the costly mistakes from the start.

2.2 Benefits of BIM-based Cost Estimation

BIM is regarded as one of the most promising developments in the construction industry. Despite the fact that the BIM tool has been around for a long time, few companies, particularly small-scale companies, have implemented it. The reluctance to adopt such technology could be explained by the lack of knowledge and realization of its benefits to the company in the long run. This study has disclosed six important factors of adopting BIM in performing cost estimation, as shown in Table 1.

TABLE 1: The Benefits of BIM-based Cost Estimation

Benefits	**Descriptions**
Provide reliable cost estimates	BIM Tools provides a quick and precise estimation. It provides a one-click analysis which would show up materials, costs and expected duration of each activity
Time saving	BIM allow estimators to extract the exact measurements and materials quantities directly from the models, eliminating the need to go through the 2D drawings manually
High efficiency and predictability	It is highly efficient as it can help to avoid human errors and manual operation errors in producing bill of quantities
Streamline collaboration between design professionals	It brings all stakeholders to be involved in the early design stage so that workflows are transparent and clear to all parties.
Interoperability between stakeholders	Will not experience loss of information when all parties work with the same easily accessible and updated digital model
Easily review design options and makes changes	BIM gives freedom for stakeholders to make design changes at any stage of the project. Any amendments will be automatically updated in B/Q
Cost and resource saving	It enables estimators to trace any immediate changes made in the project and assess changes in the design to ensure the project stays within budget.

2.3 Challenges of BIM-based VR in Cost Estimation

BIM-based VR is still in its infancy and has not yet been widely adopted in Malaysian construction industry. The low adoption rate can be explained through the challenges in Table 2:

TABLE 2: The Challenges of BIM-based VR in Cost Estimation

Challenges	**Descriptions**
Lack of knowledge and training	Many stakeholders do not realize the benefits and return on investments for using such technology
Resistance to technology adoption	The older generations are used to the conventional construction practices. They fear of the uncertainty into adopting such technology
High setup implementation and maintenance cost	Integration of BIM-VR technology involved the usage of high-quality hardware in order to guarantee a good user experience.
High cost of software	BIM yearly renewal fee ranges from RM7000 to RM8000. Plus, the price might increase 5% to 7% each year, which is too expensive to begin with (Yaakob *et al.*, 2018).

Challenges	Descriptions
Lack of streamlined/ interoperability among software	The increasing materials and textures loaded into Revit software could potentially increase the size of Revit files, resulting in software crashes and slow performance
Presence of skill gap	Skill gap such as skill supply, skill demand and skill management are very important as skills are needed to performed simulations of real activities (Davila Delgado *et al.*, 2020).
Difficulty in updating model	It is difficult to update BIM models and construction schedules automatically from VR systems
Cannot easily translate the changes made in VR systems into BIM models	Corrections or discussions made within the VR environments cannot be automatically translated into BIM models. Researchers are investigating on ontology for two-way seamless and automatic communication between BIM model and VR system(Davila Delgado *et al.*, 2020).

2.4 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) is a well-established model for predicting an individual technology adoption decision. The TAM is adopted in this study to measure on how user's intention to use are influenced by the benefits, perceived usefulness, perceived ease of use, attitude and challenges that come along. Diagram below depicted the TAM with its construct:

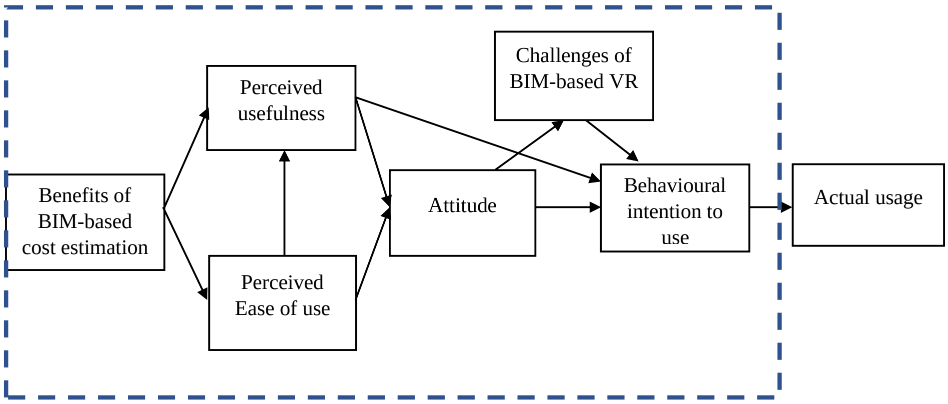


FIG. 1: Modified Technology Acceptance Model for BIM-VR cost estimation

The TAM for BIM-based VR begins with the benefits of BIM as the external variables (uncontrollable interference factors) that would potentially influence the Perceive Usefulness (PU) and Perceive Ease of Use (PEU) of the user (Legris, Ingham and Collerette, 2003). PU is described as the extent to which using the technology might improve job performance. Whereas PEU is the extent to which learning to use the technology would be effortless, which would assess the ease of operating the technology. The TAM proposes that attitude is a significant antecedent to a user's behavioral intentions. Besides, attitude is indicated as psychological tendency reflected in appraising a given entity with a degree of favor or disfavor (Huang and Qian, 2021). Challenges of BIM-based VR are hypothesized to influence the customer's intention to use since challenges are postulated as the reason against the use of the BIM-VR in this context. This idea is adopted through the Behavioural Reasoning Theory conducted by Westaby (2005). According to the theory, reasons (positive/negative) serve as an important linkage between the attitude and intention to use as it can help individuals to justify and defend their actions. In the presence of negative reasons, users may have a positive attitude toward innovations, but this does not always translate into adoption (Claudy, Garcia and O'Driscoll, 2015). In other words, users may have favourable thoughts regarding BIM-VR, but they may not have a strong desire to use it once they acknowledge the strong arguments against them, such as the challenges in adopting BIM-VR.

3. RESEARCH METHODOLOGY

Quantitative approach is selected in this study to achieve the aim. The data is collected using purposive sampling method, 180 invitations were sent, receiving 104 samples with 92 valid responses, contributing to 51% response rate. 92 valid samples are adequate according to sample size computed by G-Power calculator when power is at 0.8 as suggested by Cohen (1988). The respondents were identified from the AEC (Architectural, Engineering, Contractor) and quantity Surveying disciplines, who possess knowledge in either BIM, VR and quantity take-off.

From the sample, 42.9% are at the junior executive level, followed by 34.1% from middle executive and 23.1% senior executive. The preliminary screening result indicate that, 86.8% of the respondents are aware about BIM, VR and cost estimating in which eligible to proceed with the questionnaire. However, 13.2% of respondents are completely ignorant on the topic BIM and were ineligible to proceed answering the questionnaire. It can be concluded that most of the respondents in Malaysia do have the knowledge in BIM and but not all of them are practicing it. There were also a portion of respondents who are aware on the BIM-based VR technology, however there were little to no respondents who are practicing the use of VR in the projects. This could be due to the high implementation and maintenance cost, in addition to no mandatory policy from the government to adopt BIM in the projects.

In order to justify the reliability and sampling adequacy of the samples, Cronbach's Alpha is performed to examine on the internal reliability, meanwhile Kaiser-Mayer-Olkin (KMO) is performed to evaluate on the sampling adequacy, as shown in Table III. Both Cronbach's Alpha and KMO surpassed the minimum threshold value as suggested by Hair *et al.* (2019), which is 0.7.

TABLE 3: Cronbach's Alpha &KMO Coefficient

Factors	Cronbach's alpha coefficient	Kaiser-Mayer-Olkin coefficient
Benefit of BIM	0.877	0.824
Challenges of BIM-based VR	0.860	0.810

4. RESULTS AND DISCUSSION

4.1 Principal Component Analysis

Principal Component Analysis (PCA) is adopted in this study as the dimensional-reduction approach to reduce the large dimensionality of datasets while maintaining vital information. In this study, factor loading of 0.6 is set as the cut-off point as suggested MacCallum *et al.* (1999)for sample size of less than 100. The findings revealed that 'Saving cost and Resources' is the most crucial factor contributing to the benefits of BIM-based cost estimation with a factor loading of 0.846. This could be well-explained by BIM's ability to perform automatic quantity take-off, allowing the estimators to track any instant changes to ensure the project stays within budget. Whereas 'Easily review design options and make changes' is the least important component with a factor loading of <0.6, as shown in Table 4. This could be because reviewing design options mostly assists in deciding the most cost-effective model, but it does not directly impact the accuracy of cost estimation.

TABLE 4: PCA- Benefits of BIM-based Cost Estimation Results

Components	Factor Loading
Provide reliable cost estimation	0.839
Save time in doing cost estimation	0.832
Saving cost and resources	0.846
High efficiency and predictability	0.843
Streamline collaboration between design professionals	0.632
High interoperability between design professionals	0.725
Easily review design options and make changes	

4.2 Structural Equation Modelling (PLS-SEM)

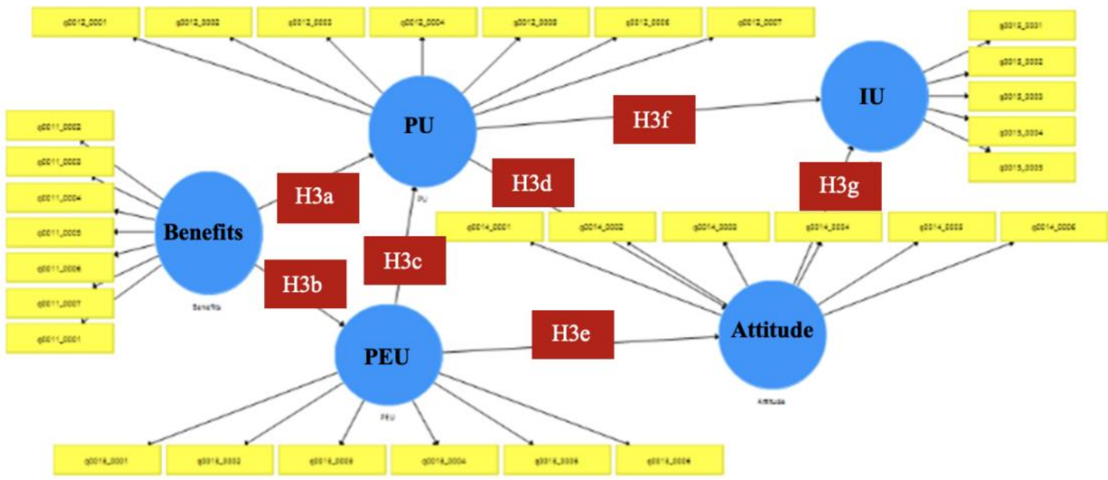


FIG. 2: TAM for BIM-based VR Model

Reflective measurement model, as shown in Figure 2, is built to examine the Composite reliability, Convergent validity (AVE), and Discriminant Validity of the model (Huang and Qian, 2021). According to Hair (Hair *et al.*, 2019), composite reliability is evaluated to ensure the model achieved high levels of reliability. Then, convergent validity is to address the degree to which a construct converges to explain the variance of its elements. Finally, discriminant validity is to determine how distinct a construct is experimentally from other constructs in the structural model. All the above assessments have achieved the minimum threshold value, hence illustrated that the model is fit for further assessment. The results are depicted as below:

Construct Reliability and Validity

Matrix | Cronbach's Alpha | rho_A | Composite Relia... | Copy to Clipboard:

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Attitude	0.8823	0.8943	0.9111	0.6322
Benefits	0.8757	0.8975	0.9046	0.5806
IU	0.8881	0.8960	0.9181	0.6921
PEU	0.8672	0.8818	0.9007	0.6041
PU_	0.8702	0.8878	0.9015	0.5725

FIG. 3: Composite reliability and convergent validity (AVE) of measurement model

Discriminant Validity

Fornell-Larcker... | Cross Loadings | Heterotrait-Mon...

	Attitude	Benefits	IU	PEU	PU_
Attitude	0.7951				
Benefits	0.6312	0.7619			
IU	0.8374	0.5221	0.8319		
PEU	0.6278	0.6310	0.5362	0.7773	
PU_	0.7260	0.7090	0.6373	0.5498	0.7566

FIG. 4: Discriminant validity of measurement model

Under structural model assessment, Collinearity Statistics (VIF), R^2, path coefficient will be reported accordingly. Collinearity Statistic (VIF) is performed to evaluate the strength of the relationship between the independent variables. When two or more independent variables are significantly intercorrelated among one another, multicollinearity problem occurs. Multicollinearity can lead to skewed or misleading results, hence affecting the model accuracy, and resulting in interpretability issues. According to Becker *et al.* (2015), VIF value of more than 10 implies the presence of multicollinearity. As suggested by Menard (2002), 5 is often used as the conservative cut-off VIF value. However, the ideal VIF should be around 3 and below. Since the VIF values, as shown in Figure 5, are substantially lower than the cut-off value of 5, no further action is needed, given the non-parametric character of these variables (Salama and Hons, 2011).

Collinearity Statistics (VIF)

Outer VIF Values | Inner VIF Values

	Attitude	Benefits	Challenges_	IU	PEU	PU_
Attitude			1.0000	2.1914		
Benefits					1.0000	1.6614
Challenges_				1.1602		
IU						
PEU	1.4332					1.6614
PU_	1.4332			2.1357		

FIG. 5: Collinearity Statistic result

Coefficient of determination, R^2 is used to determine the goodness of fit in regression analysis. R^2 measures the variation that is explained in each of the endogenous constructs. Thus, it reveals information on a model's in-sample predictive power (Benitez *et al.*, 2020). As a guideline, R^2 of 0.75, 0.50, and 0.25 are considered substantial, moderate, and weak—the higher the R^2 values, the stronger the explanatory power. Other than that, a high R^2 also indicates that the model fits the observed data. However, R^2 can vary based on different disciplines (Hair *et al.*, 2019). In this study, the Attitude, Intention to Use (IU), and Perceived Usefulness (PU) are having moderate correlation. The R^2 value of 0.7031 in IU implies that 70.31% of the dependent variable is predicted by the independent variable, suggesting a good fit for the model. Whereas Perceived Ease of Use is considered weak association as the value is <0.25.

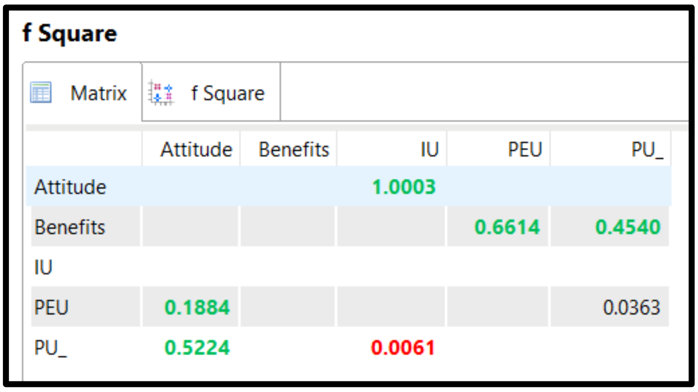
R Square

Matrix | R Square

	R Square
Attitude	0.6021
IU	0.7031
PEU	0.3981
PU_	0.5201

FIG. 6: Coefficient of Determination, R^2 results

In this study, effect size is used to define measure of association between variables. It indicates how much proportion of variance in one variable is explained by the other (Sullivan and Feinn, 2012). Hair et al. classified effect sizes as small (f2 >=0.02), medium (f2 >=0.15) and large (f2 =0.35) (Hair *et al.*, 2019) and it ranges from 0 to 1. Majority of the f2 value in this study has surpassed 0.15 medium threshold, indicating a meaningful effect. Whereas the f2 value of PU >IU is lower than the minimum threshold of 0.02, indicating a meaningless effect. This result is corresponding to the structural equation modelling result (Table 5) which showed the statistically insignificant effect from PU>IU.



f Square

Matrix | f Square

	Attitude	Benefits	IU	PEU	PU_
Attitude			1.0003		
Benefits				0.6614	0.4540
IU					
PEU	0.1884				0.0363
PU_	0.5224		0.0061		

FIG. 7: Effect Size, f^2 results

Next, the relevance of the path coefficients is to be evaluated for hypothesis testing. The P-value result has shown up to four asterisks, each indicating a different level of significance. Based on the result shown in Table VI, paths coefficient of Attitude > IU, Benefits > PEU, Benefits > PU and PU >IU indicate a very high significant level at 99.99%. At the same time, PEU > Attitude indicates its significance at 99.9%. The path of PEU > PU shows a significant level of 95%. Conversely, the path from PU > IU exhibited the least significance level as the p-value is <0.05, indicating the relationship is statistically insignificant and shall be rejected (Kock, 2016). The hypothesis path coefficient results are shown in Table 5.

TABLE 5: Structural Equation Model results

Path Coefficients	P-value	Decision
Attitude -> IU	0.0000****	Supported
Benefits -> PEU	0.0000****	Supported
Benefits -> PU	0.0000****	Supported
PEU -> Attitude	0.0011***	Supported
PEU ->PU	0.0482*	Supported
PU -> Attitude	0.0000****	Supported
PU -> IU	0.2841	Not Supported
*Notes: *p<0.05, ***p<0.001, ****p<0.0001*		

4.3 Mediation Result

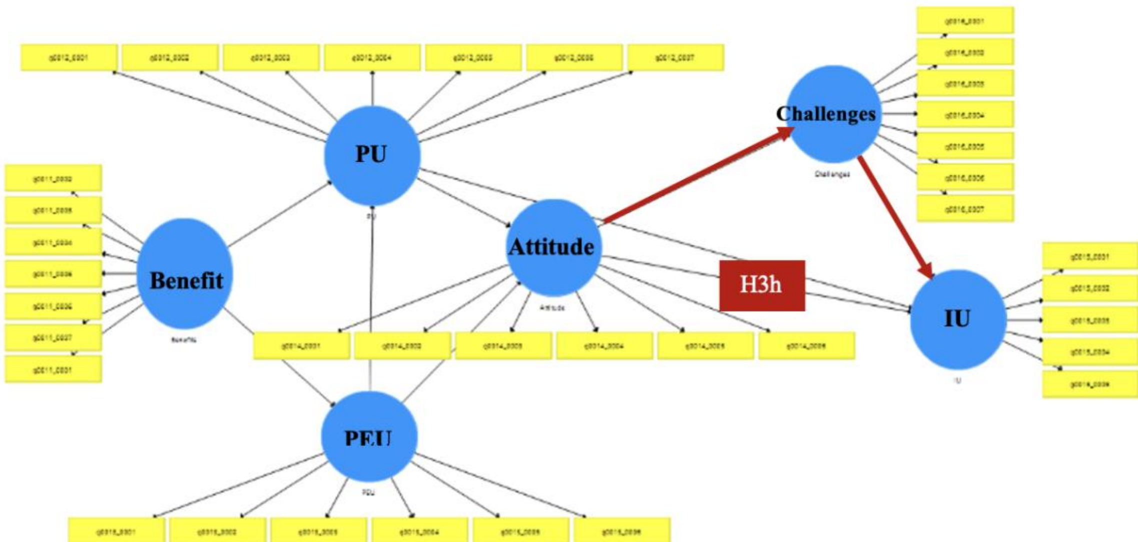


FIG. 8: Modified TAM for BIM-based VR model with mediator

To provide a better perspective of the relationship between constructs, bootstrapping analysis were conducted in Smart-PLS with 5000 bootstrapping samples (Preacher and Hayes, 2008). From the findings, the attitude exerts insignificant indirect effect ($\beta = 0.0254$, $p = 0.1814$) on the behavioural intention to use BIM-based VR through the mediator of challenges of BIM-based VR, which implies there is no mediating effect exists. Having no effect in mediator suggests that the challenges to adopt BIM-based VR are insignificant to prevent the construction professionals from having the intention to adopt it.

Total Indirect Effects

Mean, STDEV, T-Values, P-Values | Confidence Intervals | Confidence Intervals Bias Corre

	Original Sa...	Sample Me...	Standard D...	T Statistics (...	P Values
Attitude -> Challenges_					
Attitude -> IU	0.0254	0.0318	0.0279	0.9101	0.1814
Benefits -> Attitude	0.5936	0.6032	0.0645	9.1969	0.0000
Benefits -> Challenges_	0.2132	0.2407	0.0668	3.1919	0.0007
Benefits -> IU	0.5116	0.5216	0.0662	7.7299	0.0000
Benefits -> PEU					
Benefits -> PU_	0.1074	0.1093	0.0680	1.5784	0.0573
Challenges_ -> IU					
PEU -> Attitude	0.0929	0.0947	0.0620	1.4991	0.0670
PEU -> Challenges_	0.1509	0.1680	0.0600	2.5173	0.0059
PEU -> IU	0.3449	0.3461	0.0934	3.6928	0.0001
PEU -> PU_					
PU_ -> Attitude					
PU_ -> Challenges_	0.1961	0.2183	0.0725	2.7057	0.0034
PU_ -> IU	0.4365	0.4334	0.1030	4.2385	0.0000

FIG. 9: Total Indirect Effect for p-value results

4.4 Hypotheses Testing

TABLE 6: Hypotheses Testing

Hypotheses	Relationship	Decisions
H1	Benefits > BIM-VR adoption	Supported
H2	Challenges > BIM-VR adoption	Supported
H3a	Benefits > PU	Supported
H3b	Benefits > PEU	Supported
H3c	PEU > PU	Supported
H3d	PU > Attitude	Supported
H3e	PEU > Attitude	Supported
H3f	PU > IU	Not Supported
H3g	Attitude > IU	Supported
H3h	Attitude > IU (mediator)	Not Supported

The hypotheses testing revealed an important association between the benefits of BIM-based cost estimation and BIM adoption. Having mastered the benefits of BIM will increase the intention of estimators to adopt BIM operations in their professions. According to study, it would have been easier to persuade BIM adoption in the construction industry if users were informed on the Return on Investment (ROI) in BIM (Latiffi and Tai, 2019). This is to train the users to anticipate the long-term benefits of BIM, as the ROI will eventually break even or even exceed in a few years.

Next, the findings suggested that the challenges of BIM-based VR technology would not impede the intention of users to adopt the usage. This could be due to the tech-savvy generation who are highly agile towards managing the new changes in innovative technology. They are fearless in embracing new technology as they believe advanced technology is invented to improve the quality of work and life. They reckon that the benefits of technology would outweigh the challenges of adopting it as technology will only continue to evolve at a faster rate to overcome the challenges at hand.

It can be summarised that Technology Acceptance Model does help in understanding the acceptance level of BIM-based VR technology among the construction professionals within Malaysia. A series of events regarding how they perceived the technology by the usefulness and easiness to use has concluded that with the benefits of BIM-VR technology in mind, the users would not resist the new changes that come with it. It will take time for BIM-VR technology to gain widespread acceptance across the nation. However, it is safe to claim that the new generation is comfortable with the changes and would adopt such technology despite the challenges that come with it.

5. CONCLUSION AND FUTURE WORKS

Improving efficiency and accuracy of cost estimation has always been the common goal in construction projects. In response to this problem, this study has proposed a solution that seeks to enhance the efficiency and accuracy of cost estimation based on the extensive review of BIM-based VR for cost estimation. The goal is attained by linking the BIM model from various engineering disciplines to the cost database to enable one-click quantity take-off. The BIM model can then be exported to VR development software and incorporates different kinds of interaction to the object, such as review costing, scheduling, types of material, and performing real-time changes between BIM and VR model. With the TAM model, the researchers can conduct a test on the behavioural intention of construction practitioners when it comes to adopting BIM-based VR in construction projects. This study is significant to the software developers and other organizations to assess the acceptance of BIM-based VR among the practitioners in Malaysia. Important factors revealed in this study, such as perceived ease of use of the software can be exploited by software developers to construct BIM-VR platforms that are more likely to be used and approved by users. Furthermore, educating the construction practitioners on the benefits of adopting BIM-based VR appears to be significantly effective as it is among the important factors for adopting BIM-based VR technology.

The limitation of this study lays on the quantitative method as it is conducted on a voluntary basis, thus might be subjected to self-selection biases. Due to this setting, majority of the invited respondents were between 5-15 years of working experience where BIM and digital twining are widely discussed during this period. The author tried to reduce the method error by examining the collected sample through internal consistency and sampling adequacy which had shown a good pass at the threshold.

The future work can focus on enhancements work on the BIM-based VR to ensure the user-friendliness of the VR interface. For example, the VR experience could be improved by simplifying the BQ schedule so that clients can fully understand the scheduling and costing without the need for construction professionals to explain them. Next, it is suggested that an emphasis be placed on raising knowledge of BIM-use VR's and how they may assist the construction sector. This is critical because examining the potential of VR and other cutting-edge technologies will expand the possibilities for the emergence of new workflows and opportunities that could boost the production and efficiency in work.

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