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Assessing Readiness for BIM-AR Adoption in Malaysia Construction Industry: A Study of Causal Relationship

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ABSTRACT

This research explores the readiness of BIM-AR adoption in Malaysia construction industry. Three dimensions are proposed: awareness, challenges, and readiness. It studied how these variables affect the construction players on the readiness and willingness to implement BIM-AR in their project. The research hypotheses are: (1) Awareness of BIM-AR influences the Readiness of its adoption and (2) The challenges influence the Readiness of BIM-AR adoption. Participants included 65 construction players which consist of G5-G7 contractors and BIM consultants located in Klang Valley. The questionnaire survey method is applied in this research to analyse the relationship between variables and verify the hypothesis based on the collected 65 valid questionnaires. The partial least square method structural equation model (PLS-SEM) was used to carry out structural equation modelling to study the relationship between latent variables. The model has revealed that increasing awareness and eliminating challenges could help to enhance readiness in adopting BIM-AR. The findings show that, the positive and significant path coefficient between "Awareness" and "Readiness" suggests that a higher level of awareness is associated with increased readiness for BIM-AR adoption. Meanwhile, the negative and significant path coefficient between "Challenges" and "Readiness" indicates that higher perceived challenges are associated with lower readiness for BIM-AR adoption. According to this study, the main challenges impacting the readiness for BIM-AR implementation is the concern among construction stakeholders regarding the associated costs of adopting this technology. The finding also proves that the level of readiness to implement BIM-AR among respondents are high where the highest ranked score of readiness indicates that the respondents are willing to provide training programs and support for BIM-AR implementation. This shows that the majority of respondents are willing to implement BIM-AR in their project. Hence, these findings have provided a valuable insight on the readiness of BIM-AR in Malaysia construction industry.

Keywords:
Building Information modelling; augmented reality; BIM-AR; consultant; contractors; construction; Malaysia

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1. Introduction

The construction industry plays a significant role in the economy of many countries around the world. It contributes to the gross domestic product (GDP) of a country by building residential buildings, commercial buildings, and infrastructure projects. In Malaysia, this industry stands as a noteworthy contributor, representing approximately 4.5% of the nation's GDP in 2021 [3]. In the construction sector, Building Information Modeling (BIM) is employed to enhance communication, foster collaboration, and facilitate decision-making across the entire lifecycle of a building.

Since early 2007, the Director of the Public Works Department (PWD) has introduced BIM in Malaysia [9]. The significant benefits of BIM implementation are increasing productivity and efficiency). BIM's capacity to integrate time and cost enables real-time updates and facilitates the evaluation of an effective tracking and monitoring process across project phases. To date, BIM improves productivity and efficiency, evaluates the time and cost associated with a design change, and eliminates design-related conflicts in a construction project [21].

Augmented Reality (AR) technology has gained traction in the construction sector owing to its capacity to enhance communication, collaboration, and efficiency within the construction process. By enabling users to overlay virtual information onto the real world, AR technology creates a mixed reality experience, enriching the user's perception of their physical environment [24].

Advancing along with Industry Revolution (IR 4.0), BIM was integrated with AR which brings lots of benefits to the designer, consultant, architect, and client. The integration of BIM with AR will produce a powerful tool that allows construction professionals to visualize the building design in the real world, improving the accuracy and efficiency of construction [16].The integration of BIM and AR in construction demonstrates a powerful synergy, offering a more collaborative, efficient, and technologically advanced approach to the entire construction process.

To the best knowledge of the researcher, there is lack of studies on BIM-AR readiness conducted in Malaysia. Generally, BIM-AR adoption in Malaysia still considered in an early stage [4]. Therefore, the aim of this research is to investigate the readiness of BIM-AR in Malaysia construction industry. The objectives of this research were to determine the association of awareness of BIM-AR to its adoption among construction industry professionals in Malaysia, assessed the challenges associated with the implementation of BIM-AR in Malaysia, and modelled the readiness of BIM-AR implementation among construction industry professionals. This research will focus on the perspective of G5-G7 contractors and consultants to assess the readiness for BIM-AR adoption among contractors and consultants in Malaysia construction projects.

1.1 Building Information Modelling (BIM)

BIM is a technology that involves creating a digital model of a construction project [7]. This model contains intellectual objects with their specific data and instructions, allowing for the representation of each object and its internal components and characteristics. This information can then be easily presented to stakeholders. BIM consists of five primary features, which are visualization, coordination, simulation, optimization, and plotting capabilities. BIM is defined by the National Institute of Building Science (NIBS) of the United States as the “sharing of knowledge resources for information about a facility, providing a reliable basis for decisions throughout its life cycle; BIM exist from the beginning of a construction project to its completion” [23].One of the major advantages of BIM is its ability to digitally simulate and model a project from its initial stages, ultimately bringing it to a real product. According to Udhayakumar and Karthikeyan [18], “The concept of BIM facilities beyond 3D parametric virtual representation into 4D parametric in Scheduling; 5D parametric in

Costing; 6D parametric in Sustainability and 7D parametric in Facilities Management,". It offers more than just transmitting electronic copies of paper documents or presenting them in three dimensions. By using the 3D model, BIM enables the contractors to identify possible conflicts during the design phase, where BIM can save money by reducing construction by 20 to 30% [25].

1.2 Augmented Reality (AR)

The concept of "augmented reality," which was originally derived from "virtual reality," typically pertains to the overlay of computer-generated virtual images and objects onto actual environments, thereby generating a combination of virtual and real [28]. In another definition, AR is a technology that overlays virtual information onto real-world objects and environments, creating a seamless integration between the two [16]. This integration has been noted to enhance our perception of the real world, effectively blurring the line between reality and virtuality. The AR project could integrate various elements into the physical environment to enhance the desired result [15]. These items consist of various forms of multimedia such as videos, images, 3D models, animation clips, scenes, and the manipulation of objects through complete or partial replacement, as well as the addition of orientation, depth, and position.

1.3 The Development of BIM-AR from the Global and Malaysia Perspective

On a global level, the introduction of BIM-AR has led to significant advancements in various aspects of the construction industry [14]. Architects and designers can visualize their designs in a real-world context, allowing them to identify potential clashes or design flaws before construction begins. This helps minimize errors, reduce rework and improve overall project efficiency. During the construction phase, BIM-AR enables workers to access digital information and instructions overlaid onto the physical environment [4]. Thus, this will help in enhancing productivity, accuracy and safety by providing real-time guidance and highlighting potential hazards. In September 2021, Singapore has been actively promoting the adoption of Building BIM and Augmented Reality AR technologies in the construction industry.

In Malaysia, BIM-AR and has been increasingly adopted to transform various aspects of the construction process. The adoption of BIM has been driven by several factors, including government initiatives, industry regulations and the desire to improve construction project outcomes. For example, the Construction 4.0 launched by the Malaysian government in 2016 encourages the use of BIM in public and private sector projects [5]. Meanwhile, AR has been utilized for tasks such as visualizing designs, conducting virtual walkthroughs and improving on-site communication [6]. By using AR, stakeholders can experience the project in a more immersive and interactive manner, enabling better decision-making and reducing errors.

1.4 Bridging the Research Gap

According to the research gap table below, it is possible to infer that there is no similar research that has been conducted to determine the readiness of BIM-AR in Malaysia construction industry. Therefore, there is need for this study to increase awareness, to address the challenges of BIM-AR adoption in construction as well as to encourage the use of BIM-AR in Malaysia construction sector.

Table 1
Research gap analysis

No.	Author's name,Year	Title	Focus	Findings	Research Gap	Description
1	Yusof *et al.*, (2018)	Challenges in adopting BIM and AR technologies in Malaysian construction projects.	Investigate current BIM-AR projects in Malaysia, examining integration methods, usage, and outcomes.	Limited practical examples of BIM-AR integration found; benefits include improved project visualization and error reduction.	Limited Studies on BIM-AR Integration	Few studies focus on the integration of BIM and AR technologies specifically in the Malaysian context.
2	Ahmad, M.H., & Ali, N.M. (2018).	Adoption of Building Information Modeling (BIM) in the Malaysian Construction Industry: Benefits and Barriers.	Evaluating the current technological capabilities and limitations in Malaysia.	Found gaps in internet connectivity, hardware, and software that hinder BIM-AR adoption, suggesting areas for improvement and investment.	Insufficient studies on the existing tech infrastructure to support BIM-AR.	Insufficient studies on the existing tech infrastructure to support BIM-AR.
3	Liao, L., & Teo, E.A.L. (2018).	Organizational Adoption of Building Information Modeling in the Construction Industry.	Identifying cultural and organizational challenges to adopting new technologies.	Found that hierarchical organizational structures and resistance to change are major barriers, suggesting the need for cultural shift strategies.	Cultural Barriers	Sparse research on cultural and organizational barriers to BIM-AR adoption.
4	Wong *et al.*, (2019)	Technological Readiness in Developing Countries: BIM Adoption in Malaysia.	Identify specific technological, regulatory, and infrastructural factors influencing BIM readiness in Malaysia.	Key factors influencing readiness include inadequate technological infrastructure, insufficient regulatory support, and fragmented industry practices.	Context-Specific Readiness Assessment	Most readiness assessments are based on developed countries, lacking applicability to Malaysia.
5	Ahmed and Kassem (2020)	A comprehensive framework for assessing BIM readiness in the construction industry.	Develop framework on technical, organizational, regulatory, and socio-cultural dimensions tailored to Malaysia.	Developed a validated framework that effectively assesses readiness, highlighting critical areas for development and targeted improvements	Comprehensive Evaluation Framework	Absence of a multi-dimensional framework evaluating readiness for BIM-AR adoption.
6	Ibrahim *et al.*, (2021)	Stakeholder Perspectives on BIM Adoption in Malaysian Construction Industry	Gather insights to understand their views, concerns, and readiness regarding BIM-AR implementation.	Revealed diverse perspectives: firms cite cost and skill gaps as barriers, while government bodies emphasize policy and standardization needs.	Stakeholder Perspectives	Insufficient focus on understanding the perspectives of different stakeholders.

2. Methodology

The flow chart of methodology for this research is shown in Figure 1. The flowchart illustrates all the processes of this research methodology.

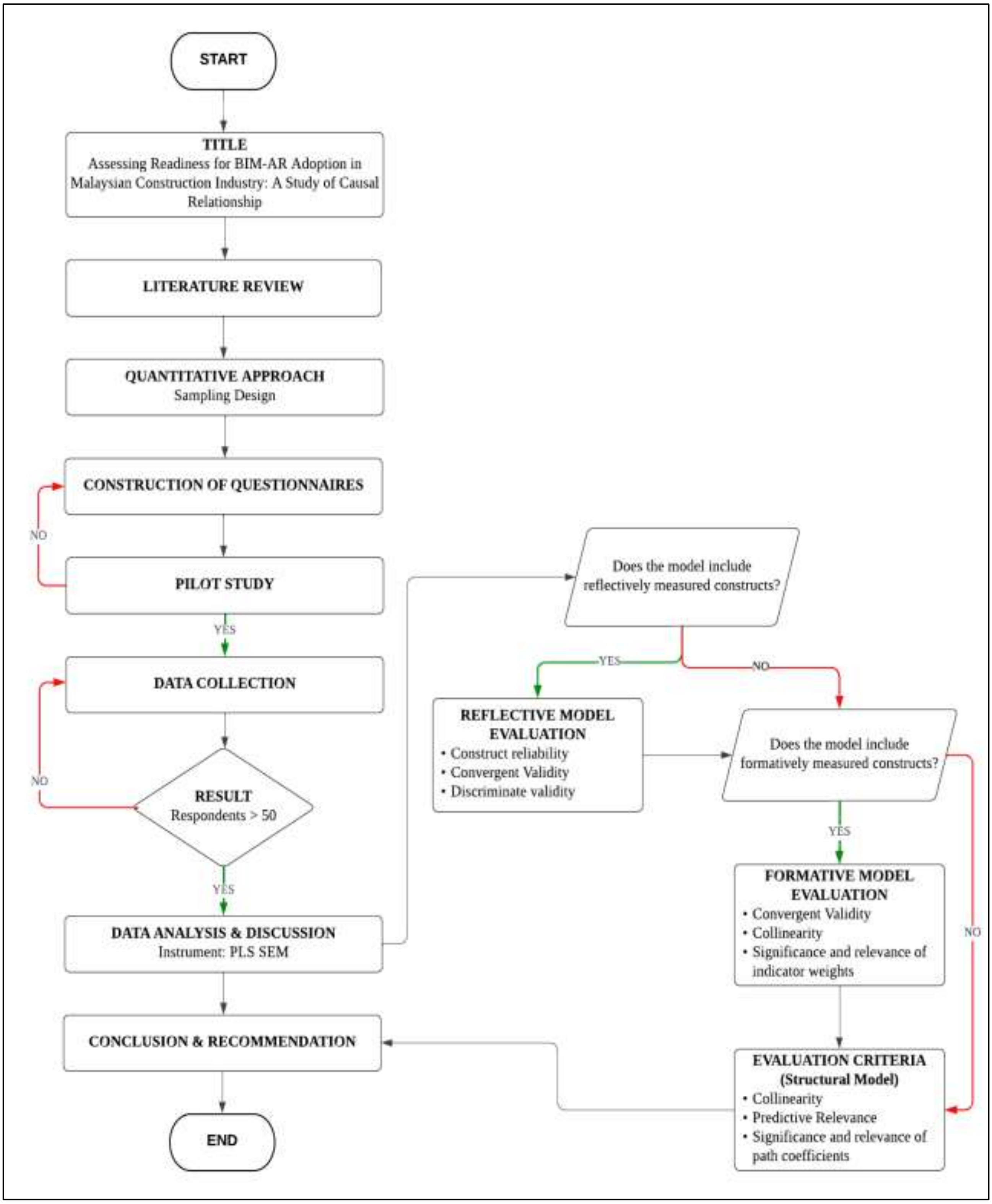


Fig. 1. Research flowchart

2.1 Quantitative Approach

The method of research that is used in this research is quantitative approach due to the range, complexity, and performance of the targeted respondents. Quantitative research often involves collecting data from a large number of participants or observations to ensure statistical reliability and generalizability of findings to a broader population [28]. This method strives to generalize about the broader population from which the data was collected. This research uses judgmental sampling to select participants from a large population. In judgmental sampling, instead of randomly selecting participants as in probability sampling techniques, judgmental sampling relies on the researcher's judgment, expertise, and knowledge of the population under study [19]. Researchers may choose participants based on specific criteria, such as expertise, experience, or unique characteristics, which they believe will provide valuable insights into the research question.

The quantitative approach focuses on collecting data that can be objectively measured and analyzed numerically. This data can include variables such as numbers, percentages, ratings, or scales. It also aims to minimize subjective biases and opinions by relying on objective measurements and statistical analysis [22].

2.2 Population and Sample Size

2.2.1 Population

This research investigates the utilization of BIM-AR by contractors and consultants within the construction industry, with a specific focus on the Klang Valley region in Selangor, Malaysia. According to the Construction Industry Development Board (CIDB) Malaysia records, there are 9,171 registered contractors categorized under grades G5 to G7 operating in the Klang Valley, Selangor [31], as detailed in Table 2 Additionally, there are 60 registered consulting firms within the same geographic area.

Table 2
The population of the registered contractors by grade in Klang Valley, Selangor (CIDB, 2023)

Area	Contractor Grade	Total Number of Registered Contractor
Federal Territory of Kuala Lumpur	G5	1289
	G6	257
	G7	1748
Gombak	G5	180
	G6	36
	G7	158
Petaling	G5	1460
	G6	380
	G7	2071
Klang	G5	280
	G6	73
	G7	290
Hulu Langat	G5	453
	G6	77
	G7	419
TOTAL		9171

2.2.2 Sample size

Sample is a smaller representative group that is selected to participate in the research study, and the findings from the sample are then generalized to the larger population. In this research, the sample size of respondents was determined using judgmental sampling. According to Othman *et al.,* [21], judgmental sampling is a data collection technique wherein the researcher selects individuals based on their expertise and knowledge relevant to the study's focus. For this study, the target population includes contractors classified under grades G5 to G7 and consultants operating in the Klang Valley. The minimum number of respondents targeted for this study is 60.

2.3 Questionnaire Design

The questionnaire is structured into five sections: Section A, Section B, Section C, Section D and Section E. Section A collects demographic information about the respondents. Section B assesses the awareness of BIM-AR among contractors and consultants. Section C addresses the challenges associated with the implementation of BIM-AR in the construction sector. Section D evaluates the readiness for BIM-AR implementation in construction projects. Sections B, C, and D consist of Likert-scale questions designed to align with the research objectives. Finally, Section E gathers the respondents' perspectives on the adoption of BIM-AR within the Malaysian.

Likert scale questions are frequently employed to investigate how respondents evaluate a series of statements by selecting or marking numerical categories (e.g., 1, 2, 3, 4, 5). Such items are effective in eliciting respondents' feelings, opinions, attitudes and other reactions to various issues [23]. In this study, a four-point Likert-scale was utilized, offering the alternatives: strongly agree, agree, disagree, and strongly disagree. This approach was chosen to avoid neutral responses, ensuring that the researchers obtained clear positive or negative feedback relevant to the study's objectives.

2.4 Pilot Study

A pilot study in research is a small-scale preliminary investigation conducted prior to the main study to test the feasibility, methodology and potential challenges associated with the research project [10]. Its purpose is to help researchers gather initial data, evaluate research instruments or procedures, and make necessary adjustments before conducting the larger study. In this research, the validity of the questionnaire design was assessed by an academic supervisor from Universiti Tun Hussein Onn Malaysia (UTHM) and an experienced BIM manager. Reliability analysis was conducted by three instructors, one industry professional, and five researchers who evaluated a series of structured questions. This process aids in eliminating irrelevant questions that do not align with the study objectives or are deemed inappropriate for this research.

Cronbach's alpha is a measure of internal consistency reliability, commonly used in classical test theory. However, in PLS-SEM researchers typically use other reliability measures because PLS-SEM operates under the framework of latent variable modeling rather than classical test theory. In this study, reliability test for each variable were measured using composite reliability (rho_a) in PLS-SEM. The value for both composite reliability (rho_a) is between 0 and 1. In early phase 0.7 acceptable, but in later phases values of 0.8 or 0.9 are more desirable [20]. Table 3 shows the acceptance criteria for composite reliability in PLS-SEM measurement model.

Table 3
Acceptance criteria of composite reliability in PLS-SEM

Composite reliability (rho_a)	Interpretation
>0.09	Excellent
0.80-0.90	Good
0.70-0.79	Acceptable
0.60-0.69	Questionable
0.50-0.59	Poor
<0.50	Unacceptable

Table 4 illustrates the composite reliability analysis for Sections B, C, and D of the pilot study questionnaire. The analysis indicates that all the data are valid. The rho_a value for Section B is 0.856, which falls within the range considered to be reliable and indicates a good level of reliability. For Section C and Section D, the rho_a values are 0.961 and 0.922, respectively. These values suggest an excellent level of reliability, as rho_a values exceeding 0.9 are indicative of high reliability.

Table 4
Composite Reliability analysis for section B, Section C and Section D

Section	Measure	Rho_a	Interpretation
B	Awareness	0.856	Good
C	Challenges	0.961	Excellent
D	Readiness	0.922	Excellent

2.5 Data Collection and Analysis

Questionnaires were distributed to the targeted respondents to determine the awareness and challenges of BIM-AR among consultants and G5-G7 contractors, as well as their readiness to implement BIM-AR in construction projects. The distribution took place during the KL BIM Day 2023, held in Kuala Lumpur, Malaysia, from July 11 to 13, 2023. KL BIM Day 2023 aims to promote and drive the adoption of BIM to transform the future of the built environment. The event gathers international and local BIM leaders to foster a more sustainable, efficient, and productive construction industry, providing a platform for professionals and stakeholders to exchange knowledge, experiences, and insights related to BIM practices, thereby promoting collaboration and innovation within the field. In addition to in-person distribution at the event, questionnaires were also disseminated via email and social media platforms such as WhatsApp and Telegram. This approach was chosen for its time efficiency, improved response quality, cost-effectiveness, flexibility, and ease of access for respondents. A total of 150 questionnaires were distributed during KL BIM Day 2023 and 65 of these were completed filled in.

The data collected were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). This study will correlate on three parameters which are awareness, challenges and readiness of BIM-AR in Malaysia construction industry. PLS-SEM is a statistical technique used for analyzing complex relationships among multiple latent variables and their indicators [13]. PLS-SEM estimates the path coefficients, indicating the strength and direction of the relationships between latent variables. It can handle complex models with multiple latent variables and their associated indicators, allowing for a comprehensive examination of the relationships among various constructs.

3. Results and Discussion

3.1 Demography of Respondents

3.1.1 Analysis of respondents' positions and contractor grade'

Figure 2 (a) illustrates the distribution of respondents' positions within the company. Consultants represent the majority, comprising 57% (22 respondents), while contractors constitute 43% (28 respondents). This distribution underscores the prevalence of consultant positions among the respondents.

Figure 2 (b) provides a detailed breakdown of contractor grades. The highest percentage is attributed to Contractor Grade G7, which accounts for 64.0% (18 respondents) of the 28 contractors. This is followed by Contractor Grade G5, represented by 22.0% (6 respondents), and Contractor Grade G6, represented by 14% (4 respondents). These figures indicate a diverse distribution across various contractor grades.

(a)

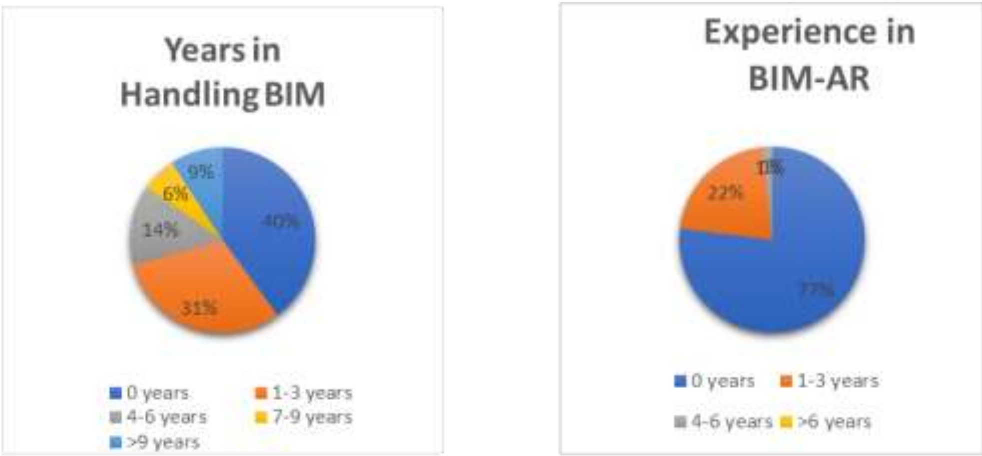
(b)

Fig. 2. (a) Position in company (b) Contractor grade

3.1.2 Analysis of respondents' years in handling BIM and experience in BIM-AR'

Figure 3 (a) depicts the distribution of respondents' experience with BIM. The data reveals that the majority of respondents, 40.0% (26 individuals), have no prior experience in BIM, categorized as "0 years." The next significant group, comprising 31.0% (20 respondents), falls into the "less than 1-3 years" category. Additionally, 14% of the respondents have "4 to 6 years" of experience, while 9.9% (6 individuals) have "7 to 9.9 years" of experience. Notably, only 6% of respondents, totaling 4 individuals, possess more than 9 years of experience in BIM. These findings indicate that a substantial portion of the respondents are relatively new to BIM.

Figure 3 (b) illustrates each respondent's involvement with AR in BIM projects, regardless of their participation. The survey categorized respondents into two groups: those with zero years of experience and those with 1 to 3 years of experience. The majority, comprising 77.0% (50 respondents), reported no experience with AR in BIM projects. A smaller proportion, 22.0% (14 respondents), indicated having 1 to 3 years of AR usage in BIM projects. Notably, only one respondent, accounting for 1%, reported integrating BIM and AR for 4 to 6 years. These findings suggest a prevalent lack of awareness or utilization of AR among the surveyed workforce, highlighting a potential gap in AR adoption within BIM practices.



(a) (b)

Fig. 3. (a) Years in handling BIM (b) Experience in BIM-AR

3.2 The Association of Awareness and Challenges to BIM-AR Adoption

The association between awareness and challenges in the adoption of BIM-AR in the construction industry is crucial. The measurement model assesses the extent to which observed variables represent the underlying constructs, providing information on the reliability and validity of the measurement instruments. Construct reliability for each latent construct was calculated using composite reliability (CR). According to recommended standards, the CR value for all constructs should be ≥ 0.7 [12], indicating good reliability. In this study, all CR values exceed the threshold of 0.7, ensuring discriminant validity is achieved. Consequently, the data demonstrate satisfactory reliability and validity for the measurement instruments.

To assess the convergent validity of the reflective block of the model, the Average Variance Extracted (AVE) should exceed 0.5, indicating adequate convergent validity [23]. According to Figure 4, the latent constructs comply with this recommended minimum level of 0.5. These findings demonstrate that the measurement model exhibits convergent validity and internal stability. Furthermore, the results indicate that the measurement components for each construct were accurately assessed and did not measure any other construct within the research model. Consequently, all the latent constructs were determined to be satisfactorily valid.

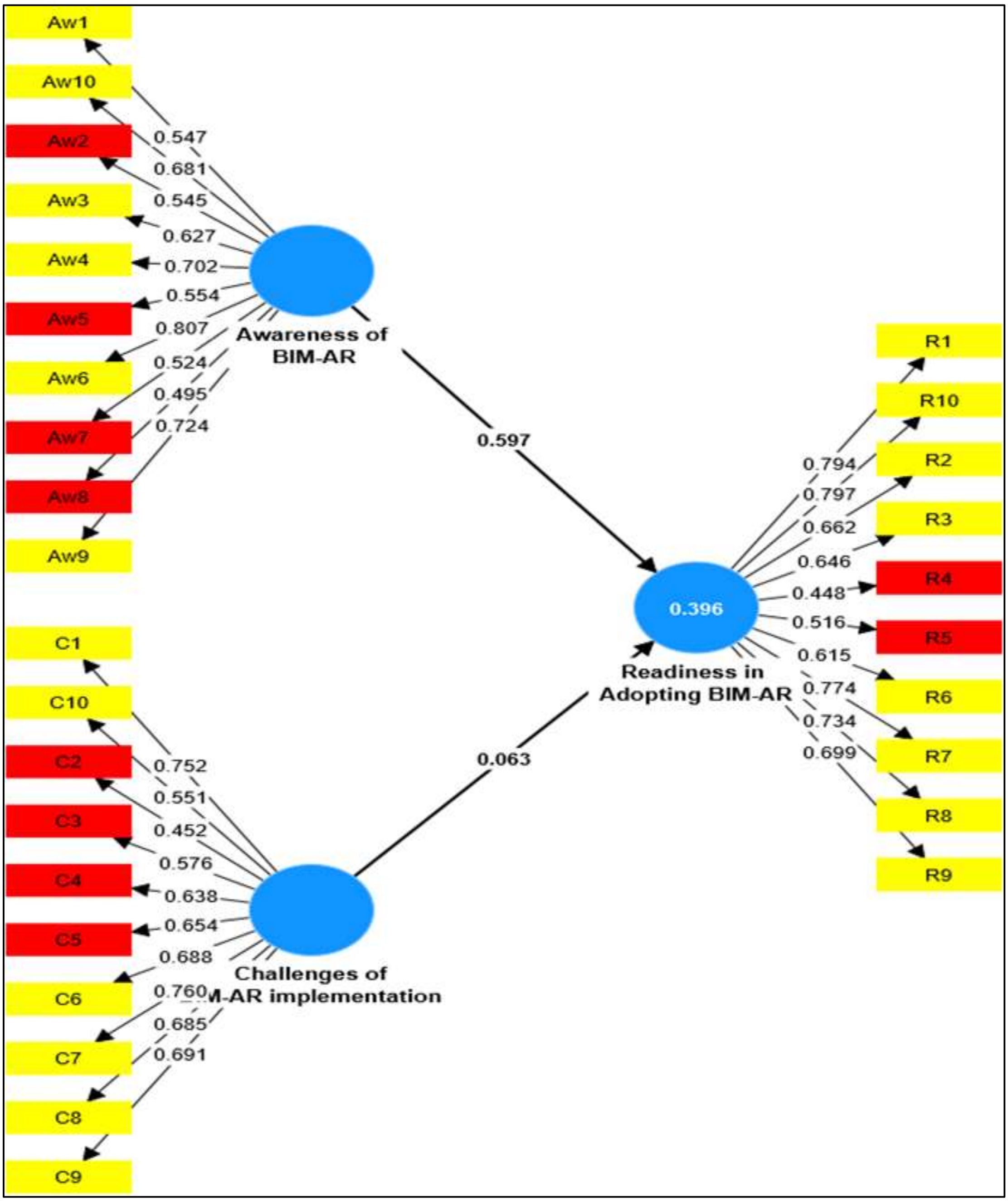


Fig. 4. PLS initial model

The second method employed to assess validity is the Heterotrait-Monotrait Ratio (HTMT). According to the stricter criterion, HTMT values should be ≤ 0.85, while the more lenient criterion allows for values ≤ 0.90 [12]. As indicated in Table 4, all HTMT values are below the stricter threshold of 0.85. Therefore, it can be concluded that respondents recognized these constructs as distinct. Taken together, the results from both validity tests—convergent validity and HTMT—demonstrate that the measurement items are both valid and reliable.

3.3 Assessing the Causal Relationship between Challenges and Awareness to the Readiness for BIM-AR Adoption

Figure 5 shows the path analysis of the final model for the causal relationship between challenges and awareness to the readiness of BIM-AR adoption in Malaysia construction industry.

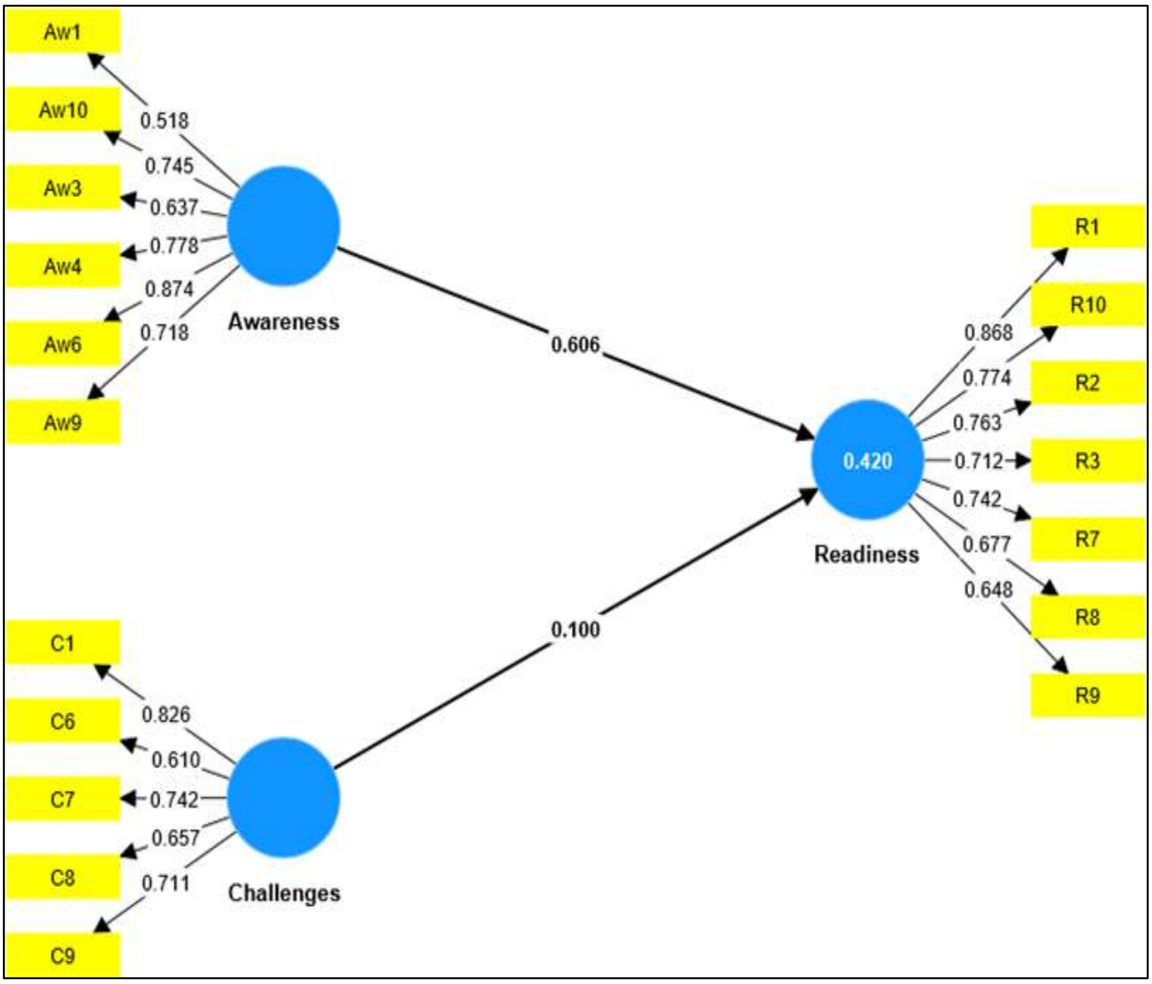


Fig. 5. Path analysis (Final Model)

This study investigates the relationship between awareness, challenges, and readiness for the adoption of BIM-AR within the construction industry. To explore these dynamics, two primary hypotheses have been formulated.

The first hypothesis (H1): awareness of BIM-AR significantly influences the readiness for its adoption. This hypothesis is grounded in the notion that increased awareness and understanding of BIM-AR technologies among industry professionals lead to a higher likelihood of adopting these innovations. When contractors and consultants are well-informed about these aspects, they are more likely to be prepared and willing to integrate BIM-AR into their projects.

The second hypothesis (H2): the challenges associated with BIM-AR influence the readiness for its adoption. This hypothesis acknowledges that while awareness is crucial, the practical difficulties and barriers encountered in implementing BIM-AR can significantly affect readiness levels. Challenges may include technical issues, high costs, lack of skilled personnel, and resistance to change within the industry. Understanding these challenges is essential for determining how they impact the willingness and preparedness of contractors and consultants to adopt BIM-AR technologies.

To test the proposed hypotheses and the structural model, path coefficients between latent variables were assessed. A path coefficient value should be at least 0.1 to account for a significant impact within the model [32]. As indicated in Table 5, both proposed hypotheses are supported. Supported hypotheses are significant at the level of (β, $p < 0.05$).

Table 5
Causal relationship of awareness and challenges with readiness of BIM-AR adoption

Hypothesis	Relationship	Std Beta	Std Dev	t-values	p-values	BCI LL	BCI UL	f^2	VIF
H1	Awareness → Readiness	0.606	0.091	6.677	0.000	0.093	0.377	0.554	1.142
H2	Challenges → Readiness	-0.035	0.163	2.616	0.040	0.111	0.428	0.315	1.142

For Hypothesis 1 (H1), the data reveal that awareness is positively related to readiness for adopting BIM-AR ($\beta = 0.606$, $p < 0.05$), thus confirming a significant positive relationship between awareness and readiness for BIM-AR adoption. This suggests that as awareness of BIM-AR increases among industry professionals, their readiness to adopt these technologies also increases.

For Hypothesis 2 (H2), the data show that challenges are negatively related to readiness for BIM-AR adoption ($\beta = -0.035$, $p < 0.05$). This indicates a significant negative relationship between challenges and readiness for BIM-AR adoption, suggesting that as the challenges associated with BIM-AR increase, the readiness to adopt these technologies decreases.

3.4 Discussion

Figure 6 presents a simplified model highlighting the highest loading scores for each construct, providing a visual representation of the most significant items. Table 5 details the specific items with the highest scores for both awareness and challenges in the implementation of BIM-AR. These elements underscore the key factors influencing BIM-AR adoption, illustrating which aspects of awareness and challenges are most impactful according to the data.

3.4.1 Determining the association of awareness of BIM-AR to its adoption among construction industry professionals in Malaysia

Based on the findings presented in Figure 6 and Table 6, it is evident that awareness of BIM-AR has a positive and significant impact on the readiness for BIM-AR adoption within the construction industry. The PLS-SEM analysis conducted in this study explores the relationships among various constructs, particularly the association between awareness of BIM-AR and its adoption. The results highlight the substantial influence of awareness on the level of BIM-AR adoption among construction stakeholders. Specifically, the data suggest that a 52% increase in BIM-AR awareness could potentially enhance BIM-AR adoption. This finding underscores the importance of promoting and increasing awareness of BIM-AR technologies within the construction sector to facilitate their successful implementation.

Moreover, the significant path coefficient ($\beta = 0.606$) as shown in Table 5 indicates that for every unit increase in BIM-AR awareness, there is a corresponding increase of 0.606 units in the adoption of BIM-AR in construction projects. This implies that efforts aimed at improving awareness levels can directly contribute to higher levels of BIM-AR adoption, thus driving advancements in construction practices and project outcomes.

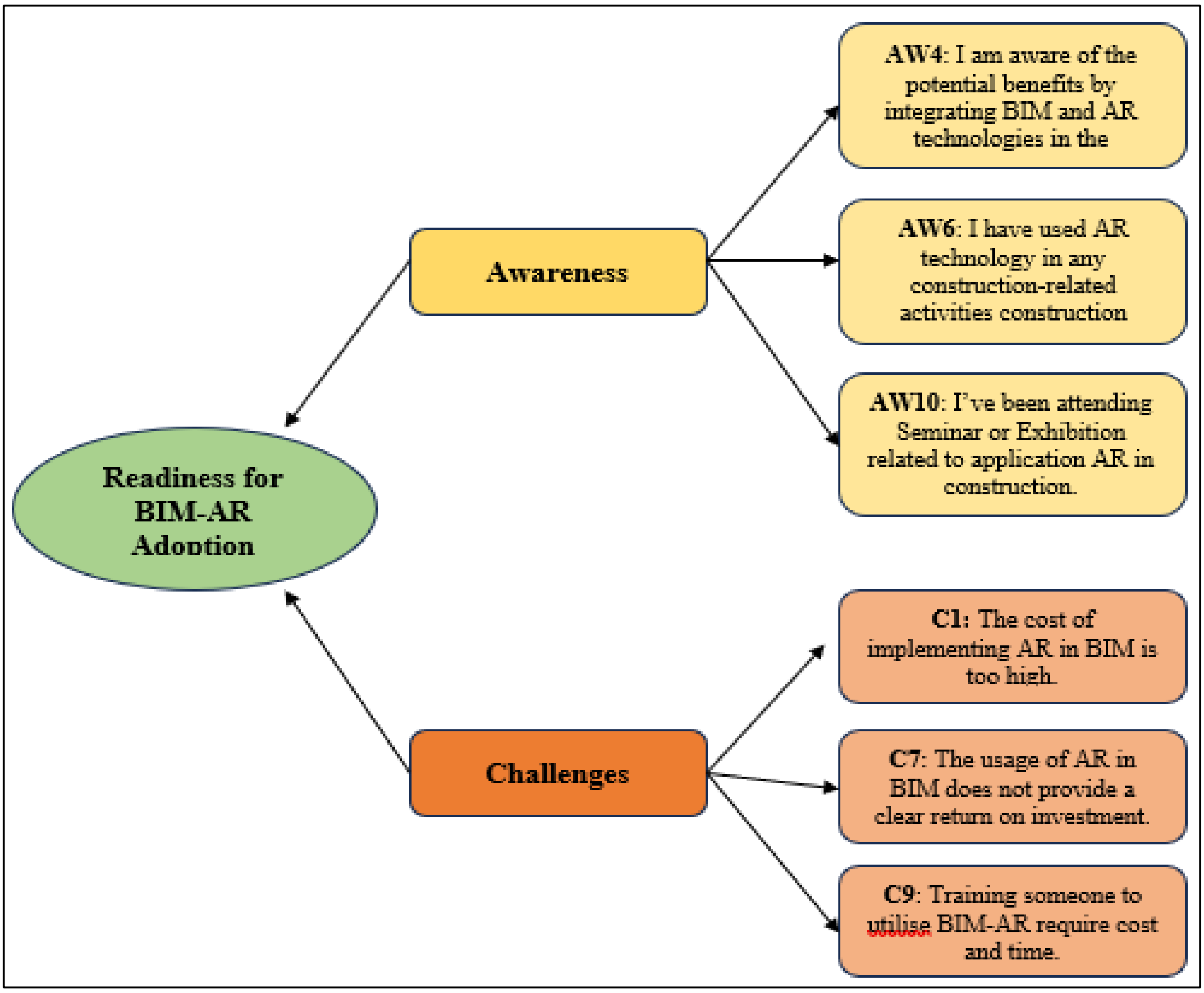


Fig. 6. Top ranked factor for awareness and challenges that associated with readiness of BIM-AR adoption

Table 6
The top ranked factor for awareness and challenges

Awareness of BIM-AR among construction Professionals		
Rank	Item	Loading score
1	AW6: I have used AR technology in any construction-related activities	0.874
2	AW4: I am aware of the potential benefits by integrating BIM and AR technologies in the construction industry	0.778
3	AW10: I've been attending Seminar or Exhibition related to application AR in construction	0.745
Challenges in BIM-AR implementation among construction professionals		
Rank	Item	Loading score
1	C1: The cost of implementing AR in BIM is too high.	0.874
2	C7: The usage of AR in BIM does not provide a clear return on investment.	0.778
3	C9: Training someone to utilise BIM-AR require cost and time.	0.745

According to Table 6, the item with the highest score for awareness is AW6: "I have used AR technology in any construction-related activities," with a loading score of 0.874. This result suggests that a significant proportion of the respondents have practical experience with Augmented Reality (AR) technology in construction activities. Following this, the second-ranked item is AW4: "I am aware of the potential benefits of integrating BIM and AR technologies in the construction industry." This finding indicates that a majority of the respondents possess awareness and understanding of the potential advantages associated with the integration of BIM and AR technologies in the construction sector.

Lastly, AW10: "I've been attending Seminar or Exhibition related to application AR in construction" occupies the third position. This result suggests that the level of awareness among respondents is high, as they have actively sought exposure to AR applications in the construction industry through attendance at seminars and exhibitions. This finding underscores the importance of such events in augmenting awareness levels concerning BIM-AR among construction professionals [5]. For instance, the CIDB Malaysia has organized exhibitions such as KLBIMDAY 2023 [31] to provide exposure to the latest technologies implemented in the construction sector.

3.4.2 Assessing the challenges associated with the implementation of BIM-AR in Malaysia

According to the results presented in Table 5, the path coefficient (β) score of -0.35 indicates a negative relationship between challenges and readiness, suggesting that when challenges are mitigated, the level of readiness for adoption increases. These findings are consistent with prior research [11].

Based on Table 6, the primary challenge for BIM-AR adoption has been identified, with a loading score of 0.826, is C1: "The cost of implementing AR in BIM is too high." This finding underscores the significance of cost as the primary impediment to BIM-AR adoption. To enhance readiness for BIM-AR implementation, it is imperative to employ decision support tools enabling designers to compare project efficiency across various metrics, including resources, emissions and costs.

The second rank among the challenges, with a loading score of 0.742, is C7: "The usage of AR in BIM does not provide a clear return on investment." This finding suggests that respondents perceive a lack of clarity regarding the benefits of adopting BIM-AR within the construction industry. To address this, it is crucial to provide construction professionals with exposure to the advantages of BIM-AR by showcasing successful project implementations.

The third significant challenge identified, with a loading score of 0.711, is C9: “Training someone to utilize BIM-AR requires cost and time.” Many respondents’ express concerns about the investment of time and resources required for BIM-AR training. Therefore, it is essential to address these challenges comprehensively to enhance the readiness for BIM-AR adoption in the Malaysian construction industry.

3.4.3 Assessing the readiness of BIM-AR implementation through model developed

The study reveals a significant relationship between awareness, challenges, and the readiness for BIM-AR implementation in the Malaysian construction industry. This relationship is supported by the data presented in Table 5, where the effect sizes of awareness and challenges on readiness are measured at 0.554 and 0.315 respectively. These values indicate a substantial influence of both awareness and challenges on the readiness for BIM-AR implementation.

Specifically, according to Table 5, the path coefficient (β) from awareness to readiness is calculated as 0.606, reflecting a high level of awareness among respondents. Conversely, the path coefficient (β) from challenges to readiness is determined to be -0.35, indicating that the challenges encountered by respondents in implementing BIM-AR are relatively low, thereby potentially leading to a high level of readiness for BIM-AR usage. This finding suggests that the overall level of readiness to implement BIM-AR among respondents is notably high, likely influenced by the heightened level of awareness regarding BIM-AR technologies.

Furthermore, based on Table 6 the highest-ranked readiness item, R1: "Do you have a plan to provide a training program and support for BIM-AR implementation?" underscores the willingness of the majority of respondents to incorporate BIM-AR into their projects. This readiness to invest in training and support programs for BIM-AR implementation signifies a proactive approach among industry professionals towards embracing and leveraging these technologies within the construction sector.

Overall, the study indicates a strong relationship between awareness, challenges, and readiness for BIM-AR implementation in the Malaysian construction industry. The findings highlight the importance of fostering awareness, addressing challenges, and promoting readiness to facilitate the successful adoption and utilization of BIM-AR technologies in construction projects. This study also proves that the high level of readiness in implementing BIM-AR is due to the high level of BIM-AR awareness [24].

4. Conclusions

A study was undertaken to assess the readiness of Building Information Modeling-Augmented Reality (BIM-AR) integration within the Malaysian construction industry, with three primary objectives delineated: first, to determine the association of awareness of BIM-AR to its adoption among construction industry professionals in Malaysia; second, to assess the challenges associated with the implementation of BIM-AR in Malaysia; and third, to model the readiness of BIM-AR implementation among construction industry professionals. The empirical findings indicate a positive association between heightened awareness levels and increased readiness for BIM-AR adoption. Conversely, challenges encountered in the implementation process exhibit a negative and statistically significant path coefficient. Furthermore, the research reveals a notable level of readiness among respondents to embrace BIM-AR technologies, attributed predominantly to the elevated awareness regarding its functionalities and potential benefits. These findings underscore the significance of identifying and addressing the challenges impeding BIM-AR integration, alongside intensifying efforts to enhance awareness levels, as a pivotal measures to encourage organizational or individual readiness for adopting BIM-AR technologies within the Malaysian construction industry.

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