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Advantages And Challenges of Augmented Reality During the Construction Phase in Sarawak

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ABSTRACT

The usage of Augmented Reality (AR) has increased in the construction industry, especially during the design stage. Although AR could reduce the risk and identify errors during the construction phase, limited research has been conducted. Therefore, this study examines the advantages and challenges of AR implementation during the construction phase in Sarawak, Malaysia. Semi-structured interviews with six (6) contractors and construction and project managers were conducted. The findings revealed that the key advantages of AR are improving real-time visualisation, communication and collaboration, and increasing productivity. The study also found potential challenges such as the low maturity of AR technology, cost implications, resistance to change, and project complexity. This study contributes to the construction industry for better project outcomes such as error reduction, cost saving, project quality improvement and time reduction.

INTRODUCTION

The construction industry contributes greatly to the development of various types of infrastructure and buildings. Nowadays, the construction industry is in the midst of the Fourth Industrial Revolution (IR4.0), a convergence of various technologies that mitigate the boundaries between physical, digital, and biological realms (Schwab, 2016). The application of inventive digital technologies such as Building Information Modelling (BIM), blockchain, 3D Printing, Augmented Reality (AR), and Virtual Reality (VR) has changed progressively the process of the built assets being designed, constructed, and maintained (Buehler et al., 2018). It is believed that the implementation of AR in construction is a potential technology with space for improvement in the future. However, AR has been more widely adopted in other sectors like online

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shopping, surgery, education, and video gaming sector rather than the construction sector (Sharma et al., 2022).

Research conducted by Olatunde et al. (2023) reported the lowest level of awareness and readiness for AR usage among the IR 4.0-related technologies. Although the application of AR is not as common as the other IR 4.0 technologies such as 3D printing and BIM, AR is still being applied during the construction phase, such as project planning and modification (Oke & Arowoiya, 2022). In the United States (U.S.), the construction stakeholders are suggested to apply the technology of AR which might assist in alleviating the issues related to underground utilities. AR is capable in locating existing underground utilities through 3D visualisation on-site, thereby lowering the risks of damaging the utilities while undergoing excavation in the construction stage. Furthermore, the application of AR could reduce the time for potholing to expose underground utilities before installing a new utility line (Fenais et al., 2020). Moreover, the adoption of AR is recommended to achieve the key strategies of boosting occupational safety and health through technology (Department of Occupational Safety and Health, 2021).

Despite the benefits of AR in assisting users' visualisation, enhancing the surrounding environment and users' interaction, as well as information sharing (Davila Delgado et al., 2020; Mutis & Ambekar, 2020), its adoption is relatively low in the construction industry (Sharma et al., 2022). Park and Kim (2013) found that AR is an effective tool in defect management of construction projects to ensure quality. However, challenges exist in the adoption of AR such as difficulties in automated construction schedule updating (Delgado et al., 2020), complexity in operations (Masood & Egger, 2019), and high cost of implementation (Lakmal et al., 2021). Such challenges seem to limit the adoption of AR, which in turn reduce the productivity and efficiency of the construction industry. Zaher et al. (2018) recommended AR to be used in error reduction and hence reduced the risk of rework, indicating its effectiveness compared to the manual update of information. Statistics have shown that rework of construction projects in Malaysia could increase the overall project values from around 3.1% to 6.0% (Yap et al., 2017). This seems to imply the limited application of AR in the construction industry.

This study aims to identify the advantages and challenges of AR during the construction phase in Sarawak, to foster its implementation. Effective visualisation of a project's status and information sharing through the application of AR could ensure proper communication of information and hence reduce the amount of rework. This is essential to ensure the efficiency of construction projects to be completed within the allocated time and budget. In Sarawak, construction projects are planned for both rural and urban areas to ease the connectivity and travel of the citizens, such as the RM226.31 million allocated in the year 2024 for upgrading the road in rural areas of Sarawak (Bong, 2024), and the RM6.1 billion North Coastal Highway that are going to commerce from 2025 to 2030 (New Straits Times, 2024). The adoption of AR to these construction projects may enhance the efficiency of the projects, in terms of cost and time.

LITERATURE REVIEW

The technology of AR creates a computer-generated data's environment that overlaid with the user's real-life visual field (Meža et al., 2015). In general, it blends the virtual elements with the environment in reality. As a part of intelligently mixed reality, AR can be defined as "an evolution of traditional virtual reality environments" and is "the most ambitious expression of ambient intelligence" (Elshafey et al., 2020, p. 161). Wang et al. (2013) referred AR as an "information aggregator" that can gather and combine data from various sources, including BIM and sensors that are aware of their surroundings. Halder et al. (2022) supported that the collaboration of a remote AR and BIM model can perform remote inspection and monitoring work by providing real-time visualisation.

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Previous research studied the application and future trends of AR in the fields of medical, manufacturing, education, robotics, marketing, tourism, and navigation (Mekni & Lemieux, 2014; Oke & Arowoiya, 2022). In the construction industry, several studies regarding AR have been conducted in countries such as Nigeria, the United States, Australia, and Sri Lanka. For instance, Oke and Arowaiya (2022) discovered that statistically significant difference possessed among different construction stakeholders in the areas of "visualisation and simulation of construction work", "project planning, monitoring, and modification", etc., Fenais et al. (2020) studied the application of AR to underground construction and reported that the main barriers associated with AR were related to "modelling and alignment", "hardware" and "data management". Wang et al. (2021) proposed a framework for AR adoption in the Australian construction industry and found several concepts as the factors affecting its application, such as a conservative attitude from the management and the absence of feasibility analysis. Lakmal et al. (2021) studied the challenges faced by AR for construction project monitoring and proposed strategies to overcome the challenges of adopting AR in the construction industry. Several studies in the U.K. and the U.S. studied the advantages, challenges in adoption, and future trends of AR in the construction industry (Mutis & Ambekar, 2020; Nassereddine et al., 2022).

In Malaysia, the studies mostly focused on the challenges in the implementation of AR in the construction industry (Azlan et al., 2022; Zahrizan et al., 2022), without a specific focus on the construction phase. For example, Azlan et al. (2022) studied the barriers to the implementation of AR and strategies to increase its implementation in the construction industry. Zahrizan et al. (2022) conducted an exploratory study on the barriers to AR application in the construction industry and found that lack of knowledge is the main barrier to its application. In Sarawak, the studies conducted were mostly focused on the other IR 4.0 technologies instead of AR. For instance, Tamjehi et al. (2020) studied the awareness of BIM in the Sarawak construction industry. Zaini et al. (2022) suggested creating a mobile application to integrate AR into the learning of architectural work in a quantity surveying program in one of the higher education institutions in Sarawak. There seem to be little to no studies related specifically to the advantages and challenges of AR at the construction phase in Sarawak. Table 1 and Table 2 showed the list of advantages and challenges of AR.

Table 1. List of advantages identified from the literature

Advantages	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Improving Real-Time Visualisation of the Project		✓	✓	✓		
Improving Collaboration and Communication	✓	✓	✓		✓	✓
Improved Decision-Making	✓	✓	✓	✓		✓
Improving Stakeholder Engagement and Satisfaction	✓		✓			
Allowing Real-Time Data Collection		✓	✓			✓
Inspection Time Reduction	✓					✓
Increased Realisation and Accuracy in Interpreting Drawings	✓	✓			✓	
Error Reduction	✓		✓	✓	✓	
Project Quality Improvement	✓		✓		✓	
Rework Reduction	✓		✓			
Improving Productivity	✓		✓			
Reduction In Project Time Completion		✓		✓	✓	

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Reducing Mental Workload						✓	
Educate Workforce		✓		✓			
Identifying The Dangers		✓	✓				
Increased Safety of Clients and Staff		✓		✓			

Source: [1] Kolaei et al. (2022), [2] Oke et al. (2021), [3] Nassereddine et al. (2022), [4] Zaher et al. (2017), [5] Oesterreich and Teuteberg (2017), [6] Harikrishnan et al. (2021)

Table 2. List of challenges identified from the literature

Challenges	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**
Complexity in Operating AR		✓	✓				
Maturity of the Technology	✓	✓					✓
Software Limitations	✓	✓	✓		✓		
Hardware Limitations	✓		✓		✓	✓	
Probable Health Issues Due to Long Usage of AR Headgears	✓		✓			✓	
Data Privacy and Security	✓					✓	
Affectability from Environmental Factors				✓	✓		
Cost of Implementation	✓	✓	✓		✓	✓	
Cost of Maintenance	✓					✓	
Lack of Technological Awareness		✓	✓				
Lack of Knowledge		✓				✓	✓
Resistance to Change	✓		✓	✓		✓	✓
Lack of Management Support	✓	✓					✓
Lack of Skilled Personnel	✓	✓		✓			✓
Lack of Support from the Government		✓	✓				✓

Source: [1] Nassereddine et al. (2022), [2] Zahrizan et al. (2022), [3] Oke and Arowoiya (2022), [4] Kolaei et al. (2022), [5] Harikrishnan et al. (2021), [6] Lakmal et al. (2021) and [7] Wang et al. (2021)

RESEARCH METHODOLOGY

The semi-structured interview was adopted as AR has not yet been widely adopted in Sarawak, aiming to achieve an in-depth understanding of the perspectives of the interviewees. This method could provide an avenue for the researcher to ask for more details from the interviewees. A similar approach has been adopted by Harikrishnan et al. (2021) and Lakmal et al. (2021). This study focuses on the contractors, construction, and project managers who are involved in the construction phase in Sarawak, as these stakeholders normally act as the leaders and coordinators in the construction project which indicates their sufficient understanding of the construction industry. A purposive sampling method was adopted as the interviewees must have at least 5 years of working experience in the construction industry, and a moderate understanding of AR to ensure that the comments received from the interviewees are reliable. The list of contractors and project managers was identified through the researcher's networking.

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The interview questions were asked on the areas of experience of using AR or other advanced technologies, opinions on the advantages and challenges of AR in the construction phase, and the possibility of adopting AR in the construction industry of Sarawak. Before the actual data collection, the interview questions were sent to three (3) academicians and three (3) practitioners for content validation to obtain feedback concerning the clarity of the terms used and the appropriateness of the questions. This step is crucial for the researcher as it helps to improve the interview quality and equips the researcher with needed consistency (Pandey & Chawla, 2016).

Six (6) interviewees were recruited for this study from October to December 2023 (refer to Table 3). The interview process ceased when two (2) to three (3) interviewees repeated the similar content as other interviewees. The interviewees were informed of their voluntary participation and anonymous reference to the specific individual. All interview sessions were recorded except for one (1). A written script of the remaining interview was made. All interview transcripts were validated by interviewees before being analysed using the content analysis method. The common keywords were created and grouped under similar themes.

Table 3. Details of Interviewees

Code	Occupation	Years of Experience	Company Location	Usage of AR in Sarawak
C1	Contractor	8 years	Sibu	No
C2	Contractor	28 years	Bintulu	
C3	Contractor	23 years	Bintulu	
P1	Project Manager	5 years	Sibu	
P2	Construction Manager	20 years	Kuching	
P3	Project Manager	5 years	Bintulu	

Source: Authors (2025)

RESULTS AND DISCUSSION

Advantages of AR in the Construction Phase

Table 4 showed the advantages of AR as discussed by the interviewees.

Table 4. Advantages of AR from interviewees

Advantages	C1	C2	C3	P1	P2	P3
Real-Time Visualisation	✓	✓	✓	✓	✓	✓
Collaboration And Communication		✓	✓	✓	✓	✓
Errors Detection and Reduction	✓	✓		✓		
Increased Productivity	✓	✓			✓	
Educating Workforce	✓	✓				
Progress Monitoring	✓	✓		✓		

Source: Authors (2025)

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Real-time Visualisation

All interviewees mentioned that AR could help in the construction stage by improving real-time visualisation. AR has the function of superimposition of information and objects into the reality. The interviewees reckoned that such a function could assist visualisation of the location and arrangement of reinforcement bars after the concrete pouring. Besides, AR is also helpful in complicated construction projects. For instance, C2 stated that AR assists the users in understanding the details of the complex piping system in the Methanol Plant Project in Sarawak. Nassereddine et al. (2022) supported that AR assists in real-time visualisation in the U.S.

Collaboration and Communication

Five (5) interviewees (P1, P2, P3, C2, and C3) reckoned that AR assists collaboration and communication. They pointed out the difficulties of clients in understanding the proposed 2D drawings due to a lack of specific knowledge. P2 mentioned that the traditional method of solving such issues required sketch drawings and pictures with an explanation from the project manager. However, with the assistance of AR, the client could easily understand the process and details of the construction projects.

> "Most of the time, clients are not able to understand the 2D drawing even after numerous explanations. With the availability of 3D modelling being present to clients, I believe they can understand the project progress and difficulty." (C2)

Such a finding is in line with Oke et al. (2021) who emphasised the benefit of enhancing team collaboration and communication in the Nigerian construction industry. Moreover, C3 added that AR has a wider range of applications in other phases of a construction project. For example, AR allows clients to visualise the proposed designs in a more immersive and interactive way, providing a clearer understanding on the final product in the design phase, which is tallying with the finding from Noghabaei et al. (2020).

Errors Detection and Reduction

Three (3) interviewees (P1, C1, and C2) believed that AR could detect and reduce errors in the early stage of the construction phase. By referring to the 3D model superimposed by the AR, the workers could discover discrepancies before the commencement of actual construction works.

> "AR technology enables us to avoid construction mistakes. By finding out the errors earlier, we can alter and prevent the mistake." (C2)

P1 mentioned that such discrepancies were not obvious when in 2D drawings. This may be due to the limited capacity of 2D drawings to show detailed aspects of the structures (Côté et al., 2013). Such findings tally with Kolaei et al. (2022) who showed that error reduction is the most prominent benefit of AR. As Sarawak is having major construction projects, reducing errors undoubtedly could alleviate the time overrun issues. However, P2 has an opposing view on the immaturity of AR and hence its accuracy in error detection. Hence, P2 preferred manual checking for the identification and reduction of errors.

Increased Productivity

Three (3) interviewees (C1, C2, and P2) suggested that the usage of AR could increase productivity. C1 stated that AR could prostrate a 3D modelling which eases the understanding of construction projects. P2 supported that AR could show a model and ease the detailed explanation to clients or other stakeholders.

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An interviewee (P2) added that the traditional method like sketches or drawings would be used as reasons for time consumption. However, with the use of AR, the clients could understand the overall construction progress easily and make decisions within a shorter timeframe. This could greatly enhance the efficiency and productivity in the construction sector.

> "The evolution of technology shall be studied by everyone to have better efficiency and productivity." (C2)

Educating Workforce

Two (2) interviewees (C1 and C2) pointed out that AR assists in educating the workforce, especially fresh graduates who lack of on-site experience. Most of the fresh graduates have difficulties in visualising 2D drawings as the outcome of the project. With the assistance of AR, 3D modelling could provide guideline or full picture before the completion of the project. The increased project complexity could be eased with the application of AR, providing better assistance for workers to understand the details in 3D compared to 2D drawings. Such a finding aligns with Meža et al (2015), showing that AR can provide insight into a project before its physical realisation and offer a learning opportunity for both beginners and experienced individuals in the construction field. In this sense, the construction organisation could reduce the time of senior staff in training and monitoring the staff with lesser experience.

> "Without this technology, it might be difficult for workforces such as engineers or site workers to look for certain details in a complicated drawing. The 3D modelling of AR technology enables a greater understanding compared to 2D drawings" (C2)

Progress Monitoring

Three (3) interviewees (P1, C1, and C2) stated that progress monitoring is one of the advantages of adopting AR in the construction phase. C1 stated the time-saving for on-site inspection.

> "I will not have to spend too much time on checking the construction progress with the help of AR technology" (C1)

However, P2 opposed that remote monitoring by using AR is only preferable for solving issues that are not critical and pointed out that physical inspection is still necessary at the current stage. Such opinion is tally with the finding from Kolaei et al. (2022) who stated that the advantage of inspection time reduction is not obvious in the construction phase.

Challenges of AR in the Construction Phase

Interviewees shared several challenges that hinder the implementation of AR in the Sarawak construction industry. The challenges include AR's low maturity, cost, resistance to change, and lack of complex construction projects (refer to Table 5).

Table 5. Challenges of AR from Interviewees

Challenges	C1	C2	C3	P1	P2	P3
Low Maturity Of AR					✓	✓
High Cost	✓	✓		✓	✓	✓

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Resistance to Change	✓			✓	✓
Lack of Complex Construction Projects	✓	✓	✓		

Source: Authors (2025)

Low Maturity of AR

Two (2) interviewees (P2 and P3) agreed that a low maturity of AR is one of the challenges that hinder its implementation. P2 mentioned that the low maturity of AR creates difficulties for the users to master and utilise in the construction activities. Moreover, P3 also mentioned that the technology's low maturity will lead to high implementation costs of technology, which in turn increase the burden of stakeholders from small companies for implementation. Nassereddine et al. (2022) found that AR has a great opportunity for improvement in reaching to a state of maturity in the U.S. construction industry. This could be due to the construction stakeholders in the U.S. having a greater chance of applying AR in the construction project in comparison to Sarawak, as Sarawak mostly still remain at the theoretical stage of AR application. This undoubtedly suggest the relevant construction authority to consider the potential strategies and trainings for introducing AR in Sarawak.

High Cost

Five (5) interviewees (C1, C2, P1, P2, and P3) agreed that cost was the main challenge that obstruct the adoption of AR. The cost for the implementation of AR technology is not that affordable for most of the contractors. They have to ensure the construction project is always within the budget and adopting AR might cause budget overrun issues. This result is tally with the research conducted by Nassereddine et al. (2022) who indicated that the cost of implementation was ranked third among all challenges and ranked at the first place in the financial category. However, C2 suggested that the maturity in the adoption of AR for all projects could reduce the overall construction cost, especially in reducing the omissions or errors. Moreover, P1 mentioned the cost of hiring skilled personnel is their concern in adopting AR. Such finding is supported by Lim et al. (2024) who suggested that financial challenge exists with skill enhancement as one of the contributing factors for the IR 4.0 adoption in Malaysia.

Resistance to Change

Three (3) interviewees (C1, P1, and P3) opined that the construction players mostly resisted changes. The interviewees mentioned that the construction stakeholders mastered the original construction methods without AR and hence refused to change. This could be due to the uncertainty on the performance of AR and also lack of exposure to such technology. This result was tallied with the study conducted by Nassereddine et al. (2022) which this challenge had a moderate ranking of third among five (5) challenges under the human factors.

> "I can tell that the majority, or around 70% of them are comfortable with the current use of technology. I have seen most of the developers remain with the same method and not seeking for alternative way or any other improvement in the construction projects." (C1)

However, three (3) other interviewees with longer worker experience (C2, P2, and C3) had different opinions toward this challenge. C2 reflected on the manual measurement and calculation of beams, columns, and slabs, a process that would take several months to complete for just one (1) house. However, with the advent of computer software, these calculations are now finished much quicker. This shift

demonstrates their willingness to embrace new technologies with an open mind. Similarly, P2 shared this perspective, noting that more people will start to use AR as its benefits become more widely recognised.

Lack of Complex Construction Projects

Three (3) interviewees (C1, C2, and C3) mentioned that a lack of complex construction projects in Sarawak is one of the challenges for adopting AR. Currently, the buildings and infrastructure projects in Sarawak are constructed using traditional methods and seldom implemented with high technology. However, according to the interviewees' opinions (C1 and C2), AR is more suitable for complicated projects like the construction of power plants or high-rise buildings.

> "Most of the projects handled by my company are not that complicated, hence, I think that the adoption of AR technology is not that essential yet. However, it will be considered in complicated projects such as the MLNG Tiga Project." (C3)

CONCLUSION

This study investigated the advantages and challenges of AR implementation during the construction phase in Sarawak. The findings revealed that the key advantages of AR are improving real-time visualisation and communication. AR enhances client comprehension of 3D elements and drawings, particularly for those with limited technical knowledge. This technology accelerates explanation time and provides a clearer project visualisation. By highlighting the advantages of AR technology, the industry can leverage this knowledge to achieve a better project outcome, such as error reduction, cost saving, project quality improvement, and time reduction. The study also found potential challenges such as the low maturity of AR technology, cost implications, resistance to change, and project complexity, during the construction phase. As such, the respective authorities can take mandatory action to rectify these issues and enhance the adoption of AR in Sarawak. Future studies could identify strategies that could be used to overcome the challenges and expand the scope of investigations to include the whole of Malaysia, in bolstering the overall quality of the construction industry. This expansion could also facilitate an examination of the cultural disparities within the industry between West Malaysia and Sarawak. Such an approach could enable local authorities to develop a more tailored and adaptable system for the stakeholders involved in the construction industry.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

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AUTHORS' CONTRIBUTIONS

Chloe Xin Tian Sia conceptualised the central research idea, original draft, data collection and data analysis. Shi Yee Wong conceptualised the central research idea, original draft and revised the article. Prescilla Palis, Chih Siong Wong and Chu Sheng Ding anchored the review and revisions of the article. All authors approved the article submission.

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