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BIM-Enabled Implementation of Augmented and Virtual Reality in Sri Lankan Construction: Benefits, Barriers, and Strategies

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Abstract. The Sri Lankan construction industry is hindered by persistent challenges such as project delays, cost overruns, and quality control issues. This paper presents the potential of Augmented Reality (AR) and Virtual Reality (VR), enabled by Building Information Modeling (BIM), as transformative technologies to mitigate these problems. Following a qualitative study involving semi-structured interviews with eleven expert Quantity Surveyors, the research investigates the practical applications and implementation challenges of AR/VR. Key findings reveal significant benefits, including enhanced design visualization and process automation. However, the realization of these benefits is challenged by substantial barriers to adoption, primarily high initial costs, a critical skills gap, and cultural resistance. The paper concludes by proposing practical, expert-led strategic recommendations for government, industry, and academia. These recommendations outline a multi-stakeholder approach to foster an ecosystem for innovation, aiming to enhance productivity and sustainability in the Sri Lankan construction sector.

Keywords: Augmented Reality (AR), Virtual Reality (VR), Building Information Modelling (BIM), Construction Industry, Technology Adoption, Sri Lanka, Quantity Surveying.

1 Introduction

Project duration and cost overruns are the most significant challenges in the construction industry [1]. Perera et al. [2] stated that inadequate project planning, ineffective coordination among stakeholders, and complex regulatory approval processes are the major causes of them. Furthermore, the prevailing subpar quality control practices are the other challenges [3]. Further, there are challenges related to procurement, project management, skill shortage, technological adoption, design and drawings and health and safety [4] [5]. In addition, Dlamini and Cumberlege [1] stressed that project delays and cost overruns continue to plague the Sri Lankan construction landscape, often stemming from poor project management, inadequate planning, and insufficient risk assessment. A significant factor contributing to these inefficiencies is the slow adoption of technological advancements. Consequently, the construction sector in Sri Lanka faces challenges related to outdated technology adoption and innovation. The sluggish incorporation of modern construction techniques, Building Information Modeling (BIM), and other advanced technologies curtails efficiency gains and hinders productivity [6].

Augmented Reality (AR) and Virtual Reality (VR) have emerged as transformative technologies with significant implications across various domains. AR enhances the user's perception by integrating digital content into the real-world environment [7]. Conversely, VR immerses users in entirely virtual environments, isolating them from the real world and providing highly immersive experiences [8]. Both technologies not only enhance project efficiency but also elevate safety, collaboration, and stakeholder engagement in construction processes, leading to more informed decisions and better-built structures [9]. BIM serves as a digital platform for AR and VR applications, as it provides detailed 3D models and structured data that can be visualized and interacted with through AR-enabled devices or immersive VR systems [10]. The integration of AR and VR technologies holds significant promise for mitigating project duration and product quality issues in building construction within Sri Lanka. AR and VR solutions offer immersive visualization and simulation capabilities that can revolutionize project planning, design, and execution. By utilizing AR and VR, stakeholders can engage in virtual walkthroughs of construction sites, enabling them to identify potential design flaws, clash detections, and spatial conflicts early in the process [10].

Although the extant literature offers valuable perspectives on strategies that aim to augment enablers and mitigate barriers, certain gaps continue to exist, particularly about adaptation strategies customized to the distinct dynamics of the construction landscape in Sri Lanka. It is noteworthy that the literature review is deficient in providing thorough strategies for surmounting particular obstacles and supporting critical facilitators necessary for the successful integration of AR and VR technologies during the in-depth stages of planning and implementation.

Given this context, the aim of this paper is to investigate the potential of AR and VR to address key challenges in the Sri Lankan construction industry and propose strategic recommendations for its implementation. To achieve this aim, the study is guided by the following research questions: (1) What are the potential benefits of implementing AR and VR technologies in Sri Lankan construction industry?, (2) What are the major barriers hindering the AR and VR adoption in Sri Lankan construction industry?, and (3) What strategies can be proposed to effectively overcome these barriers and facilitate successful AR and VR adoption in Sri Lanka? Furthermore, this study specifically focuses on the perspectives of Quantity Surveyors (QSs), as they play a central role in project cost management and the interpretation of design data, making their viewpoint critical for assessing the practical impact of these technologies.

2 AR and VR in Construction

2.1 Use of AR and VR in Global Construction

The combined influence of AR and VR has reshaped the dynamics of the built environment worldwide [11]. Furthermore, AR and VR technologies have revolutionized architectural visualization and design on a global scale through immersive virtual walkthroughs [12]. These technologies transcend geographical boundaries, fostering collaboration among architects, designers, and clients, creating a more interconnected global design community [13]. In parallel with design improvements, advance technology has also taken a central role in project execution. In the construction sector, AR and VR have become integral tools for project management worldwide. Construction sites in major cities like London and Dubai utilize AR for real-time data overlays, enhancing worker productivity, while VR is employed for collaborative project planning and training [14]. Moreover, AR and VR play pivotal roles in shaping smart cities and urban planning initiatives globally [15].

The possibility of applying these global trends in the Sri Lankan context is significant. VR and AR have the potential to completely change the design and visualisation processes in Sri Lanka's built environment [16]. AR technologies can enable architects and planners to overlay digital design information onto the physical environment, allowing for a real-time visualization of proposed structures within the context of existing surroundings [17]. Additionally, VR technologies offer immersive simulations that empower stakeholders to virtually explore and experience architectural designs, providing a comprehensive sense of scale and proportion [18]. AR can enhance precision in cost estimation by overlaying digital information onto physical spaces, allowing stakeholders to visualize and assess potential challenges and opportunities during the planning phase [19]. Similarly, VR simulations enable stakeholders to experience the proposed construction virtually, facilitating a deeper understanding of the project scope [11]. AR can assist construction teams by overlaying digital information onto physical spaces, allowing for enhanced on-site planning and resource allocation. This technology enables stakeholders to visualize and optimize layout decisions, reducing errors and improving the overall efficiency of the construction process [14].

Furthermore, these technologies can address issues of resource management. AR and VR technologies have the potential to revolutionize material selection and waste management practices in the Sri Lankan built environment [20]. AR can aid architects and builders in real-time visualization of different materials within the context of a construction site, allowing for more informed decisions regarding suitability and aesthetics [21].

3 Research Methodology

A qualitative research approach was adopted to investigate the potential of AR and VR and propose strategic recommendations for their adoption in Sri Lanka. Qualitative research approach is adopted to represent the perceptions, experiences, beliefs, and viewpoint of a particular group of people and this approach is an ideal option for research regarding emerging conceptions investigations. The AR and VR adaptation is the most emerging cultural change in the construction industry. Further, The AR and VR adaptation in building environment is a hypothesis for particularly in Sri Lankan context because of that qualitative method is chosen for this research based on findings of [22].

3.1 Data Collection

Data was gathered through case studies employing semi-structured interviews, documentary reviews, and observations. The interview method is a widely used data collection technique under qualitative approach. Unlike rigid surveys, semi-structured interviews offer flexibility, interactivity, and in-depth discussion with interviewees to obtain more ideas on current and new topics. Hence, semi-structured interviews have been selected for this research followed by qualitative approach as possibility for the required-further explanation is higher in this study.

3.2 Interviewee Profile

Eleven experts from different firms in the construction industry were chosen for the interviews. A combination of purposive and snowball sampling was utilized. Purposive sampling, which is a non-probability type sampling, entails selecting respondents as per the particular purpose of the research instead of randomly selecting the respondents. It is more appropriate to use purposive sampling when opinions and perceptions of the experts are the major source for the study area [23]. In addition, snowball sampling is adopted for instances where it is difficult to identify the potential respondents from the defined population [24]. This dual approach was necessary because, in Sri Lankan context, BIM adoption has been occurred recently, and it is difficult to identify the respondents who have adequate experience in BIM based design & quantification. Therefore, the selection criteria specifically focused on Quantity Surveyors with experience in both cost estimation and BIM technologies. Table.1 provides the profile of interviewees.

Table.1 Profile of interviewees

Code	Designation	Industry Experience (Years)
R1	Quantity Surveyor	5
R2	Senior consultant Quantity Surveyor	11
R3	Quantity Surveyor	4
R4	Senior Quantity Surveyor with BIM experience	9
R5	Quantity Surveyor	16
R6	Quantity Surveyor with technological expertise	5
R7	Quantity Surveyor	4
R8	Director, Senior Quantity Surveyor	17
R9	Senior Quantity Surveyor	15
R10	Director, Senior Quantity Surveyor	20
R11	Director, Senior Quantity Surveyor	18

3.3 Data Analysis

Data analysis is referred to as a process of examining, classifying, arranging, and testing the collected data. Content Analysis is a widely accepted data analysis method under the qualitative approach [25]. Moreover, it facilitates identifying patterns among textual data. Accordingly, manual content analysis was adopted to analyze the collected data and identify recurring themes related to benefits, barriers, and strategies. This involved identifying recurring words from the transcripts, categorizing them into themes of benefits, barriers, and strategies and observing their frequency to indicate relative importance.

4 Findings and Discussion

4.1 How AR and VR Can Solve Common Construction Problems

The experts interviewed for this study confirmed that AR/VR technologies offer direct solutions to some of the most challenging problems in construction.

By agreeing with R1, R7 and R8, R2 mentioned that through AR-VR based quantity calculation, manual works in quantification can be automated thereby significant time saving can be achieved. R2 mentioned, "*information integration assists in achieving higher level of time saving*". R1 added that this information integration simplifies the quantity checking process since it is not required to refer various drawings to check one element. Experts R5 and R8 elaborated on the fact as this technology *"effortlessly regenerates the quantities and conveniently accommodate the design changes"*. Beyond automation, the immersive nature of technology was seen as a key benefit for clarity and comprehension. According to the explanation provided by R5, in the AR-VR based quantity calculation method, building elements can be virtually visualized in 3D. R4 mentioned as *"conveniently understand how the elements are connected together and where they have been placed"*. Moreover, R11 mentioned that *"clearly identify the extend of each element"*. Therefore, QS can quickly obtain a proper understanding of what is going to be quantified. It assists with quantity calculation properly. This combination of automation and visualization directly improves accuracy by reducing human error. R1 stated that AR-VR automation significantly replaces involvement of the human element in quantity calculation. R8 elaborated that, "*AR-VR based method uses advanced calculation algorithms to calculate them with 100% accuracy"*. Therefore, human related errors are minimized, and accuracy is improved.

Finally, experts highlighted the significant improvement in inter-disciplinary collaboration. According to R1 and R4, minimal collaboration and its consequential adverse impacts are there with the conventional method. However, AR-VR based quantity calculation method minimizes those consequences through increased collaboration. R7 mentioned "*AR-VR at its full potential, all stakeholders can work on a central model and communicate easily between them*".

4.2 The Main Challenges of Using AR and VR in Sri Lanka

Money and Cost Problems

All respondents emphasized that higher initial cost is a problem associated with AR-VR affordance in Construction industry. R1 mentioned that higher license cost is one of the major expenditures in this method. Further, R1, R6, R8 and R10 stated that high-capacity computers and special equipment to operate the AR-VR are needed for this. For instance, the adoption of AR will typically require AR-enabled tablets or smartphones with proprietary apps (e.g., Fologram, Augment), while VR requires pricier immersive hardware such as Oculus Rift or HTC Vive headsets and suitable software platforms (e.g., Unity or Enscape). These hardware and software requirements play an important role in substantially increasing the financial burden for Sri Lankan companies. In addition, this finding is consistent with global literature on technology adoption, where initial capital expenditure is frequently cited as a primary barrier. R11 highlighted that at the beginning considerable training cost is also required to adopt this method. Furthermore, R8 agreed to the above fact that *"Not only hardware and software costs, but it also takes high investment in training the professionals to the new digital procedure"*. However, the experts highlighted that this challenge is particularly severe in the Sri Lankan context, where funds for technological upgrades can be limited for many small and medium enterprises (SMEs) that form the backbone of the local industry.

People and Training Problems

All respondents agreed that there is a cultural resistance among the QSs related to the adoption of advanced technologies. R9 and R10 observed that the degree of resistance to this change is generally higher among older people. Moreover, R10 proposed that the attitude of the people also has a strong influence in resistance to change. This cultural resistance is made worse by a noticeable skills gap. All the respondents identified a problem that there is a dearth of competent people who can perform BIM software and are capable of handling modern technologies. R8 described as "*when I was recently trying to recruit QSs with BIM capability, incurred a considerable cost for training experts*." This dual challenge of resistance from experienced professionals and a lack of trained new entrants creates a significant hurdle for widespread adoption, a situation that may be more prominent in developing economies compared to regions with established digital construction curricula.

Technology and Quality Problems

All respondents mentioned that the quality or completeness of the model is a concern in AR and VR technology-based quantity calculation. R11 elaborated on dependency of quantity from AR and VR methods. Additionally, R3 noted that when inadequate details are provided in the model, it becomes necessary to resort to 2D drawings for measuring those items using conventional methods. Furthermore, R9 added that the QSs might face difficulties due to *"improper procedure in drafting the model so that utilizing the model for your estimating purposes becomes complex"*. This "garbage in, garbage out" problem highlights that the technology's effectiveness is highly dependent on the quality of the digital inputs. This dependency leads directly to the next major technological barrier: inadequate standards. All the participants mentioned that inadequate standard is a problem associated with AR-VR technologies. The lack of localized standards means that even with willing participants, interoperability and consistency will remain significant challenges. This is further complicated by issues of software compatibility as stated by three respondents.

4.3 A Plan for Using AR and VR Successfully in Sri Lanka

Solutions for Cost Problems

To counter the significant financial barriers, the majority of respondents proposed that obtaining support of the government as a strategy to overcome from this issue. In the Sri Lankan context, AR solutions are likely to have a more immediate impact than VR, and this is largely due to their comparatively low cost of deployment and compatibility with mobile devices in widespread use. Although VR provides fully immersive experiences, its reliance on expensive headsets and high-performance computing limits short-term feasibility for the majority of businesses. Conversely, AR can be gradually integrated using affordable devices, and this makes it better suited to resource-constrained environments. Nevertheless, the role of BIM remains central, as it supplies the 3D models and structured data that enable both AR and VR to function effectively. R9 expressed what is happening in other countries as "*subsidizing the cost of software, there are tax benefits or maybe subsidized prices for the technology related investments*". In addition, R4 suggested that selecting sharing software can be a solution to higher initial costs. Further to R4, some cheaper software options can be considered. However, features will also be fewer with cheaper options.

Solutions for People and Training Problems

Addressing the human element requires a two-directional approach focusing on current and future professionals. R7 mentioned that Professional bodies such as Institute of Quantity Surveyors Sri Lanka (IQSSL) and Institute of Engineers Sri Lanka (IESL) should conduct more continuing professional development (CPD) programs and workshops. Moreover, practical methods of automatic quantity generation should be demonstrated. R9 mentioned that some QS practitioners are thinking that they will lose their job if AR-VR is adopted. However, it is important to understand one thing that they may also lose the job unless they are familiar with AR-VR technologies. For the future workforce, agreeing with R2, R10 mentioned that incorporating modules in university curriculum to explain practical method of AR-VR based automatic quantity generation and designing is a strategy for this issue. Moreover, R6 contended that self-learning habits are reduced among students and students should try to learn these technologies themselves.

Solutions for Technology and Quality Problems

To improve the quality of technical implementation, experts emphasized the need for standardization and collaboration. Five respondents suggested that implementing standards when preparing the model could assist in overcoming this issue. R5 suggested that professional bodies should perform proactively for the successful AR-VR implementation. R5 further mentioned "*if we learn from mistakes of other countries and establish standards in advance, then there will be less problems during the time of extensive usage in the future*". Finally, a direct feedback loop to technology creators was proposed. R10 suggested that through providing constructive feedback to the software developers, this problem can be solved. R10 further mentioned that with the introduction of updated versions, this problem will be greatly minimized.

To consolidate the findings, the challenges and solutions discussed in section 4.2 and 4.3 are summarized in the Table.2.

Table.2 Challenges and the solutions in AR and VR adoption in Sri Lanka

No	Challenges	Strategies
1	Low quality or incompleteness of the BIM model	Strategic planning for structured AR/VR adoption roadmap
2	Higher initial cost	Policy interventions to establish supportive regulations and incentives
3	Cultural resistance	Collaborative action among government, academia, and industry stakeholders
4	Lack of competent persons	Capacity building through specialized training and upskilling programs
5	Checking Automated quantities.	Public awareness campaigns to promote understanding and acceptance

6	Inadequate standards	Development and enforcement of standardized guidelines for AR/VR use
7	Inadequate consideration for construction methods	Integration of construction methodologies into AR/VR workflows
8	Software incompatibility	Promoting software interoperability and compatibility
9	Inadequate integration in the model	Strengthening integration between AR/VR platforms and BIM models
10	Lesser awareness	Continuous monitoring and evaluation mechanisms to track progress
11	Less usage of BIM & other advanced technologies in SL.	Encouraging wider adoption of BIM and advanced digital technologies

5 Conclusions and Recommendations

5.1 Conclusions

In conclusion, AR and VR technologies offer transformative solutions to the challenges plaguing the Sri Lankan construction industry. These technologies enhance project visualization and planning accuracy, reducing financial risks and construction delays. While the adoption of AR and VR entails initial investments and the development of technical expertise, their long-term benefits are substantial. However, this research reveals that realizing these benefits is contingent on overcoming a triad of significant barriers: economic, human, and technical. By leveraging these advanced technologies, while concurrently implementing a targeted program that adheres to these recommendations, Sri Lanka can enhance construction efficiency, reduce errors, and foster innovation, ultimately driving the industry toward greater sustainability and growth. The findings carry important implications for multiple stakeholders: for government and multiple professional bodies, the need to establish standards and financial support mechanisms, for construction companies, the importance of phased adoption and capacity building; and for universities, the integration of AR/VR into curricula to equip the future workforce.

5.2 Recommendations

Based on the findings, this paper proposes a multi-stakeholder approach to facilitate the successful adoption of AR and VR in the Sri Lankan construction industry. The following recommendations are targeted at key groups who can drive this change.

For the Government and Industry Groups

To create an enabling environment, government and professional bodies should take the lead. This includes providing financial support through subsidies or tax incentives to offset the high initial cost for organizations, especially the SMEs. Government can provide financial support and other relevant support to develop own AR-VR related software in the country and can drastically reduce the initial cost of AR-VR. Furthermore, professional bodies like IQSSL and IESL must lead the development and enforcement of national BIM and data standards to address the technical quality and interoperability issues identified by experts. Further, the professional bodies can include AR-VR as one of competencies for APCs to encourage the professionals to learn the AR-VR. This support would not only modernize the construction sector but also boost national productivity, enhance the competitiveness of Sri Lankan firms, and foster a high-tech knowledge economy.

For Construction Companies

For individual firms, a phased and strategic approach to adoption is recommended. Encouraging construction organizations to adapt to AR-VR technology is a priority. Adapting this technology can create more benefits to compete with other organizations in future. Organizations should begin by investing in smaller pilot projects to demonstrate ROI and build internal capacity before large-scale rollouts. This reduces the investment risk and helps to build a strong business case for wider implementation. Equally important is fostering an internal culture that encourages innovation and provides continuous training to overcome cultural resistance and bridge the skills gap.

For Universities

Academic institutions are crucial for building a future-ready workforce. AR-VR technology can be included in curriculums of degree programs in universities. Teaching AR and VR at the university level can help to produce the most capable professionals for the industry. This should go beyond theoretical modules to include practical, hands-on learning. Partnerships with software vendors and industry firms could provide students with hands-on experience with the latest tools. Furthermore, universities should encourage interdisciplinary projects that bring together students from Architecture, Engineering, Quantity Surveying, and Information Technology to demonstrate the collaborative nature of modern digital construction practices.

5.3 Study Limitations and Future Research

The findings and recommendations of this study should be considered in light of its limitations, which in turn suggest avenues for future research. It should be noted that there is no practical implementation of AR-VR in Sri Lankan Project. Because of that, the data collections were dependent on the experts' perspectives and future predictions based on their experience in the industry. This means the identified benefits and barriers are perceived rather than empirically validated within a live project environment. In addition, this research limited to the Consultant & Contractor QS perspective from Sri Lanka. This provides a deep but narrow view of the subject. A wider understanding would require incorporating the perspectives of architects, engineers, clients, and policymakers.

Therefore, this research is considered as a benchmark for further studies related to the implementation of AR-VR technology in the construction industry. Future research could include a quantitative study to measure the ROI of a pilot project or longitudinal case studies tracking the adoption journey of early-adopter firms in Sri Lanka. Other research could also focus on developing a low-cost, localized AR/VR solution tailored to the specific needs and resource constraints of Sri Lankan SMEs, investigating the frameworks required to ensure data security on collaborative digital platforms, developing a predictive AI incorporated AR-VR solution for BIM based project delivery or a comparative study analyzing Sri Lanka's adoption journey against other developing nations.

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