EXPLORING THE POTENTIAL OF VIRTUAL REALITY IN CROSS-BORDER CONSTRUCTION PROJECTS: A CASE STUDY OF QATAR-INDIA COLLABORATION

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The global construction industry is undergoing a profound transformation driven by the rapid integration of advanced technologies. Virtual Reality (VR) technology among the technologies has transformative potential in the construction industry. This research investigates the integration of VR technology in cross-border construction project management, with a specific focus on projects designed in India for Qatar. It addresses the question: How can VR improve cross-border project management, and what are the key challenges and solutions for its integration? While previous research focused on VR's applications in health, safety, and cost management within single-location projects, this study examines VR's role in cross-border contexts. The study revealed that key benefits of VR include improved communication, immersive design visualisation, and enhanced stakeholder interaction. Challenges such as high costs, system compatibility issues, and the need for specialised training were identified. Solutions proposed include targeted training, ensuring system compatibility, and cost-effective leasing models. The study emphasizes robust data security and standardised protocols for VR use in cross-border settings, contributing practical insights for industry professionals and highlighting VR's potential to transform global construction practices.

Keywords: Virtual Reality; VR; technology; cross-border; construction; India; Qatar

INTRODUCTION

The global construction industry is undergoing a profound transformation driven by the rapid integration of advanced technologies. This digital revolution, often referred to as Construction 4.0, encompasses a suite of innovative tools and methodologies that are fundamentally reshaping how construction projects are planned, executed, and managed (Hesselink *et al.,* 2024). Among these emerging technologies, Virtual Reality (VR) stands out for its potential to revolutionise design visualisation,

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collaboration and communication within the construction sector (Watfa and Akili 2023).

However, cross-border construction projects present unique challenges that traditional communication and collaboration methods often struggle to address. These challenges include navigating time zone differences, overcoming cultural and language barriers, and adhering to diverse legal frameworks (Damm 2022). Time zone disparities can lead to delays in communication and decision-making, while cultural and language barriers can result in misunderstandings and conflicts among team members. Additionally, differences in legal and regulatory frameworks can complicate compliance and contractual obligations, leading to potential legal disputes. Logistical challenges, such as the coordination of materials and labour across borders, further exacerbate these issues, often resulting in project delays and cost overruns (Daoud, El Hefnawy and Wefki 2023).

The consequences of these challenges are significant. Project delays and cost overruns can lead to financial losses and strained relationships between stakeholders, including clients, contractors, and investors. Traditional communication methods, such as emails and video conferencing, are often insufficient for addressing these complexities, as they lack the immersive and interactive capabilities needed to effectively convey complex design concepts or facilitate real-time collaboration.

VR technology can be a potential solution, offering a collaborative virtual environment that transcends geographical boundaries. Enabling project teams and stakeholders to engage with project concepts in a truly immersive and interactive manner (Karami *et al.,* 2021). This immersive experience allows geographically dispersed teams to virtually navigate a project under construction, interact with digital twins of building models, and provide real-time feedback. These capabilities hold immense promise for revolutionising design visualisation, collaboration, stakeholder engagement, and overall project delivery within the cross-border construction landscape (Watfa and Akili 2023).

Despite these promising advantages, the application of VR technology in cross-border construction project management remains an under-explored area. While existing research has focused on the use of VR in health and safety (Bao *et al.,* 2024) and cost implications (Mohammadi and Garrido Martins 2024), there is a notable gap in studies examining VR's potential in cross-border construction project management. This research aims to fill this gap by investigating the integration of VR technology in cross-border construction project management, with a specific focus on projects designed in India for Qatar. By highlighting the practical implications of VR, such as improved communication, enhanced collaboration, and more efficient project delivery, this research provides valuable insights for industry professionals and contributes to the growing body of knowledge on VR in construction.

LITERATURE

Qatar-India Collaboration

Qatar's economy, heavily reliant on natural gas exports, has been diversifying through initiatives like the Qatar National Vision (QNV) 2030, which aims to bolster economic and social development. The FIFA 2022 World Cup further accelerated infrastructure development, including stadiums and mega-projects (Jarkas, Kadri and Younes 2012). However, Qatar faces challenges such as high labour costs and a scarcity of skilled professionals, prompting the country to outsource design and

technical services from India, known for its cost-effective and well-trained workforce (Agrawal *et al.,* 2011). Despite the economic advantages, cross-border collaborations between Qatar and India often encounter coordination challenges due to differences in language, work culture, and time zones, leading to miscommunication and project delays (Mahalingam and Levitt 2007).

VR's Role in the Construction Industry

VR technology has gained traction in the construction industry for its ability to enhance design visualisation, collaboration, and stakeholder engagement. During the design phase, VR allows professionals to create and interact with 3D models in a virtual environment, enabling early detection of design flaws and reducing costly rework during construction (Dunston *et al.,* 2011). VR also facilitates real-time collaboration among stakeholders, allowing them to immerse themselves in the project and adjust elements as needed, thereby aligning client expectations with design outcomes (Goulding *et al.,* 2012).

Despite these benefits, VR's adoption in construction faces several barriers, including high implementation costs, the need for significant computational power, and resistance to new technologies (Li *et al.,* 2018). Additionally, the integration of VR with existing workflows, particularly in cross-border projects, presents compatibility challenges that must be addressed to ensure seamless collaboration (Prabhakaran, Mahamadu and Mahdjoubi 2022).

VR In Cross-border Construction Projects

In cross-border construction projects, VR can offer unique advantages by enabling immersive previews of designs, fostering real-time collaboration, and enhancing communication among geographically dispersed teams (Haddud *et al.,* 2017). VR's ability to create a shared virtual environment can allow stakeholders from different locations, such as India and Qatar, to interact with 3D models and provide real-time feedback, reducing misunderstandings and improving decision-making (Wang *et al.,* 2018). Furthermore, VR can be integrated with Building Information Modelling (BIM) to create interactive simulations that enhance project planning and resource allocation (Hesselink *et al.,* 2024).

However, the adoption of VR in cross-border projects is not without challenges. High initial costs, the need for specialised training, and disparities in technology infrastructure across countries can hinder VR integration (Johansson and Roupé 2024). Additionally, while VR can mitigate some communication barriers, it cannot fully address cultural and linguistic differences, which remain critical factors in cross-border collaborations (Nee *et al.,* 2012).

While VR holds significant promise for transforming cross-border construction projects, its adoption is not a remedy for all challenges. The technology's ability to enhance communication and collaboration is well-documented, but its effectiveness depends on the willingness of stakeholders to adopt new practices and the availability of robust technical infrastructure. Moreover, the high costs associated with VR implementation may be prohibitive for smaller firms, particularly in developing countries like India, where budget constraints are a significant concern.

The integration of VR with BIM and other emerging technologies, such as Artificial Intelligence (AI), could further enhance its potential by enabling more accurate simulations and predictive analytics. However, this convergence also raises concerns

about data security and interoperability, particularly in cross-border contexts where sensitive information may be shared across jurisdictions (Delgado *et al.,* 2020).

VR has emerged as a promising tool for addressing the complexities of cross-border construction project management by offering immersive and interactive environments that can bridge geographical, cultural, and logistical divides. While prior research has examined VR's applications in areas such as health and safety (Bao *et al.,* 2024) and cost management (Mohammadi and Martins 2024), there remains a significant gap in understanding its role in enhancing collaboration, communication, and stakeholder engagement in international construction contexts. This study addresses this gap by focusing on the unique challenges of cross-border projects such as time zone differences and cultural barriers with a particular emphasis on Qatar-India collaborations. The findings aim to provide practical insights for industry professionals and contribute to the broader discourse on the transformative potential of VR in global construction project management

METHOD

This study adopts a positivist research paradigm, assuming reality is objective and measurable through systematic observation and quantification (Saunders, Lewis and Thornhill 2019). A quantitative methodology was employed to explore the use of Virtual Reality (VR) in Qatar-India cross-border construction management. This approach facilitated the collection of numerical data from a broad sample of industry professionals, enabling statistical analysis on VR perceptions of its effectiveness, challenges, and remedies.

Key concepts from studies by Nee *et al. (*2012), Li *et al. (*2018), Delgado *et al. (*2020) and Johansson and Roupé (2024) were operationalised to align the literature review with survey questions. VR adoption was measured through questions on usage frequency, specific applications in project phases, and willingness to integrate VR into future projects. Traditional cross-border methods' effectiveness was assessed using a Likert-scale, while VR's perceived benefits and challenges were captured through items focusing on communication, design visualisation, stakeholder engagement, and project efficiency.

A structured online questionnaire was distributed to construction professionals experienced in Qatar-India cross-border projects. It included demographic questions, closed-ended questions, and Likert-scale items to measure perceptions of VR's impact on project management. A combined purposive and snowball sampling approach was used to target a diverse sample of professionals, including project managers, engineers, architects, and quantity surveyors (Trochim and Donnelly 2006; Manege, Kennedy and Aloyce 2024). The questionnaire received 49 responses: 19 from engineers, 11 from project managers, 8 from architects, 4 from quantity surveyors, and 1 from another role.

Data analysis involved reliability testing using Cronbach's Alpha, which yielded a satisfactory score of 0.736, ensuring internal consistency (Tavakol and Dennick 2011). Descriptive statistics summarised participant demographics, VR usage patterns, and perceptions of VR benefits and challenges.

DATA ANALYSIS

Effectiveness of Traditional Cross-border Methods

The effectiveness of traditional design collaboration methods in cross-border projects was assessed using a 5-point Likert-scale (1 = least effective, 5 = most effective). The results (Figure 1) indicate that while a majority (51.2%) of respondents rated these methods as somewhat effective, only 9.3% considered them very effective. Notably, 18.6% of participants found traditional methods to be either neutral or somewhat ineffective, suggesting significant room for improvement in fostering more effective design collaboration in cross-border construction projects.

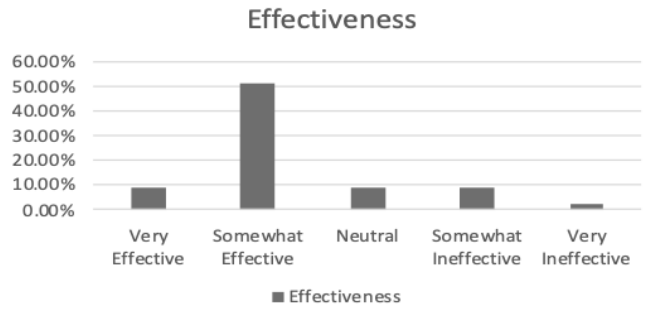

Figure 1: Effectiveness of traditional cross-border method

Effectiveness of VR in Cross-border Projects

Participants were asked to evaluate statements regarding VR's potential in cross-border construction projects (Table 1). The results revealed strong support for VR adoption, with 88% of respondents expressing a willingness to use VR in their projects. Specifically, 42% strongly agreed and 46% agreed with the statement regarding their openness to VR adoption. This positive sentiment reflects a growing recognition of VR's potential to overcome geographical barriers and enhance collaboration.

Additionally, 79% of participants believed VR could significantly improve communication, collaboration, and stakeholder engagement in cross-border projects, with 23% strongly agreeing and 56% agreeing. This indicates that VR is not only seen as a viable technology but also as a tool that can enhance communication channels in cross-border construction projects.

Table 1: Statement Ranking on VR Effectiveness

Statements	Ranks	Frequency	Percentage
You would be open to using VR if introduced in your cross-border construction project.	Strongly disagree	1	2%
	Disagree	2	5%
	Neutral	2	5%
	Agree	20	46%
	Strongly agree	18	42%
VR could improve communication, collaboration and stakeholder engagement in cross-border construction projects.	Strongly disagree	1	2%
	Disagree	1	2%
	Neutral	7	16%
	Agree	24	56%
	Strongly agree	10	23%

Challenges to VR Integration in Cross-border Construction Projects

Participants identified several barriers to VR adoption in cross-border construction projects (Table 2). Compatibility issues with existing systems emerged as the most

significant concern, with 35% of participants selecting it. This aligns with previous research by Li *et al. (*2018) highlighting the challenges of integrating VR into current workflows, especially in geographically dispersed projects where teams may use diverse software and hardware.

Skill development was another key concern, with 35% of participants emphasising the need for training and adapting to new technology. This underscores the importance of targeted training programs to equip stakeholders with the necessary skills to leverage VR effectively. Financial limitations were also noted, with 28% of participants citing high implementation costs as a barrier. This highlights the need for cost-effective solutions, such as leasing models or collaborative procurement strategies.

Notably, 44% of participants identified all presented challenges as obstacles, indicating a multifaceted apprehension toward VR adoption. This suggests that a holistic approach is needed to address technical, financial, and training-related barriers to VR integration in cross-border project management.

Table 2: Barriers to VR adoption in cross-border project management

Barriers	Frequency	Percentage
High implementation cost	12	28%
Compatibility issues with existing systems	15	35%
Training and adapting to new technology	15	35%
All the above	19	44%

Remedies to Overcome the VR Challenges

Participants proposed several solutions to overcome VR adoption challenges (Table 3). Ensuring system compatibility emerged as the most pressing concern, with 58.1% of participants advocating for "ensuring the compatibility and interoperability of VR systems." This aligns with previous research by Li *et al. (*2018) highlighting the importance of seamless data exchange and collaboration in cross-border projects.

Table 3: Remedies for adoption of VR

Remedies for the adoption of VR	Frequency	Percentage
providing comprehensive training and support for VR technology	20	46.5%
ensuring the compatibility and interoperability of VR systems	25	58.1%
Investing in robust data security measures	14	32.6%
Developing standardised protocols for VR use	11	25.6%
Reducing the costs associated with VR implementation and maintenance	12	27.9%
All the above	14	32.6%

Skill development was another key consideration, with 46.5% of participants emphasising the need for "providing comprehensive training and support for VR technology." This underscores the importance of targeted training programs to maximise VR's effectiveness. Data security was also a major concern, with 32.6% of participants advocating for "investing in robust data security measures." This reflects the growing awareness of data security risks associated with VR technology, particularly in cross-border projects.

Additionally, 25.6% of participants supported "developing standardised protocols for VR use," which could help ensure seamless collaboration across geographically

dispersed teams. Financial limitations were addressed by 27.9% of participants who favoured "reducing the costs associated with VR implementation and maintenance," highlighting the need for cost-effective solutions.

DISCUSSION

Integrating VR in Cross-border Collaborations

The findings highlight VR's transformative potential in cross-border construction projects, particularly in Qatar-India collaborations. The data reveals strong industry support for VR, with 88% of participants endorsing its integration. This aligns with literature emphasising VR's ability to bridge geographical divides and enhance communication (Wang *et al.,* 2018). However, challenges such as system compatibility, training needs, and financial constraints must be addressed.

Compatibility issues emerged as the most significant barrier, with 35% of participants citing this concern. This aligns with literature highlighting the difficulties of integrating VR into diverse workflows (Li *et al.,* 2018). Ensuring seamless interoperability, as advocated by 58.1% of participants, is crucial for effective VR adoption. Additionally, 35% of participants emphasized the need for comprehensive training, underscoring the importance of equipping stakeholders with the skills to navigate VR effectively (Johansson and Roupé 2024).

Financial constraints also pose a challenge, with 28% of participants citing high implementation costs. Cost-effective solutions, such as leasing models or collaborative procurement strategies, could mitigate this barrier, as suggested by 27.9% of participants.

VR's Role in Transforming Cross-border Construction Projects

The research builds on the foundational insights of Haddud *et al. (*2017) by demonstrating VR's potential to enrich the design process in cross-border projects. The data reveals that VR enabled immersive previews not only expedite decision-making but could also foster a more inclusive and informed stakeholder environment. This is particularly relevant in the context of Qatar-India collaborations, where stakeholders from diverse locations can actively participate in the design process without the need for physical travel.

One of the most compelling findings is VR's ability to enhance stakeholder engagement. The data indicates that VR could allow stakeholders to not only visualise the finished product but also interact with it, leading to increased emotional investment in the project. This is particularly advantageous for geographically dispersed stakeholders, such as those in India, who can participate in virtual site visits of projects in Qatar. This aligns with the literature, which suggests that VR can foster a deeper understanding of the project's physical context, thereby improving stakeholder engagement (Wang *et al.,* 2018). The data supports this conclusion, with participants highlighting VR's ability to reduce misinterpretations and foster high-quality interactions.

However, the research also reveals that VR's effectiveness is not uniform across all stages of project management. While VR excels in design visualisation and real-time collaboration, the data suggests that traditional methods may still hold value in the early stages of collaboration, particularly when building trust and rapport. This is consistent with the literature, which emphasizes the importance of face-to-face interaction in establishing trust (Hertel, Geister and Konradt 2005). This suggests that

a balanced approach, leveraging the strengths of both VR and traditional methods, may be necessary to ensure successful cross-border collaborations.

Addressing Challenges and Unlocking VR's Full Potential

The research highlights several strategies to overcome the challenges associated with VR adoption. Ensuring system compatibility emerged as the most pressing concern, with 58.1% of participants advocating for seamless integration of VR systems. This aligns with the literature, which emphasizes the importance of interoperability of technologies (Wang *et al.,* 2014). Additionally, 46.5% of participants emphasized the need for comprehensive training programs, underscoring the importance of equipping stakeholders with the skills needed to leverage VR effectively.

Data security also emerged as a significant concern, with 32.6% of participants advocating for robust security measures. This reflects the growing awareness of data security risks associated with VR technology, particularly in cross-border projects where sensitive data may be shared across borders. This suggests that investing in secure VR systems and developing standardised protocols for data sharing could mitigate these risks.

The research underscores the need for cost-effective solutions to facilitate VR adoption. The analysis reveals that 27.9% of participants supported reducing the costs associated with VR implementation, indicating a need for more affordable VR solutions. This could include leasing models, collaborative procurement strategies, or government incentives to encourage VR adoption in the construction industry.

While the findings of this study offer valuable insights into the integration of Virtual Reality in cross-border construction projects, certain limitations must be acknowledged. The sample size of 49 respondents, although sufficient for exploratory analysis, is relatively small and may not fully capture the diversity of perspectives across the broader construction industry. Furthermore, the sample is skewed toward engineers and project managers, which may limit the generalisability of the findings to other professional roles such as architects, quantity surveyors, or clients.

CONCLUSION

This research highlights the transformative potential of Virtual Reality (VR) in enhancing cross-border construction project management, particularly in Qatar-India collaborations. The study identifies significant benefits of VR, including improved communication, enhanced collaboration, and immersive design visualisation, which collectively outweigh the challenges of high implementation costs, compatibility issues, and the need for specialised training.

To address these challenges, industry professionals should focus on targeted training programs, ensuring system compatibility, and developing cost-effective solutions such as leasing models or collaborative procurement strategies. Additionally, investing in robust data security measures and developing standardised protocols for VR use are crucial for mitigating potential risks.

Future research should explore the development of cost-effective VR solutions, standardise protocols for cross-border collaboration, and address the ethical and legal implications of VR use in cross-border projects. By bridging geographical and cultural divides, VR holds the promise of revolutionising cross-border construction projects, fostering a future of seamless collaboration and innovation in the industry. The adoption of VR in the construction industry can lead to more efficient project

delivery, reduced misunderstandings, and increased stakeholder engagement, paving the way for a new era of global construction management.

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