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Development and Preliminary Evaluation of a VR-BIM Integration Framework for Decision-Making and Workflow Optimisation in Construction Projects

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ABSTRACT

Construction projects have long suffered from communication gaps and coordination challenges, resulting in design conflicts, inefficient decision-making, and rework. This study aimed to develop and conduct a preliminary evaluation of a Virtual Reality (VR)-Building Information Modelling (BIM) integration framework to support decision-making and workflow optimisation in construction projects. The proposed framework was developed through a structured literature review and enriched by expert perspectives obtained through discussions with construction professionals. The framework comprised six interconnected layers linking digital project information, immersive visualisation, stakeholder interaction, decision-making, and workflow-related outcomes. A preliminary evaluation was conducted through an expert survey involving 31 experienced construction professionals in the United Arab Emirates. Respondents generally considered the framework clear, logically organised, and useful for improving project understanding, multidisciplinary coordination, communication, and decision-making during project reviews. Overall, respondents supported the framework but expressed moderate concerns regarding its practical implementation. The survey results suggested that the framework could support construction coordination and review activities, although further empirical validation remained necessary. This study contributes a structured VR-BIM integration framework together with an initial expert evaluation. The proposed framework provides a basis for future empirical validation and implementation in construction projects.

1. Introduction

Effective review and coordination processes are critical for the successful delivery of construction projects. During the project lifecycle, particularly during design and construction, project teams manage large volumes of information, identify potential conflicts, evaluate design options, and make decisions that affect project performance and delivery [1,12]. Although digital technologies have advanced considerably, many projects still encounter challenges including communication gaps, coordination difficulties, design conflicts, rework, and delays [17,19]. For instance, previous studies

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have shown that rework remains a significant contributor to cost overruns and schedule delays in construction projects, with reported impacts ranging from approximately 5% to more than 10% of project costs in some cases [10,29]. These problems often arise from differences in how project teams interpret information or from issues overlooked during review activities [4,15,24]. The situation becomes even more challenging in large, multidisciplinary projects where decisions depend on accurately understanding complex and interdependent design information. As coordination challenges continue to place pressure on project teams, many organisations have turned to BIM to manage and communicate design information more effectively.

BIM has significantly changed how project information is created, managed, and exchanged within the Architecture, Engineering, and Construction (AEC) industry. Compared with conventional two-dimensional documentation, BIM offers integrated digital models that combine physical building geometry with project-related information, which supports design development, coordination, and project planning [3,7,23]. This approach has become a core platform for multidisciplinary collaboration across project teams [6]. However, rich BIM data alone does not ensure consistent or effective interpretation by project teams [16,28]. Coordination still requires stakeholders to understand spatial relationships, review model content, communicate observations, and make informed decisions. A detailed BIM model alone does not ensure effective coordination unless project participants can interpret and use the information appropriately.

In practice, many project reviews are still performed through desktop-based BIM environments [8,20]. These environments allow users to view BIM models on screen; however, they do not necessarily facilitate the interpretation of complex spatial configurations and cross-disciplinary interactions [26], especially in large and information-rich projects. This limitation is further intensified by the fact that project review meetings may include non-technical stakeholders with varying levels of BIM experience [28]. (Previous studies have demonstrated that BIM environments may not consistently provide an intuitive understanding of spatial information for all participants, especially non-technical stakeholders [13,22]. Such limitations in review practices can hinder meaningful engagement and timely decision-making [4].

In response to these challenges, immersive technologies have attracted increasing interest in the construction domain. Virtual Reality (VR) enables stakeholders to experience digital project environments at full scale within an immersive three-dimensional environment [21]. For example, Prabhakaran *et al*., [18] highlighted that immersive environments have the potential to expand BIM-based review processes, while other studies reported enhancements in project understanding and collaboration [2,11,26]. These research findings have contributed to growing interest in VR-BIM integration for design review and coordination activities in construction projects.

Although there is increasing interest in VR-BIM applications, much of the existing research addresses specific use cases rather than providing a holistic approach. For instance, previous research has focused on VR-BIM for immersive design visualisation, safety training, stakeholder engagement, or facility management [5,14]. Other studies have identified implementation challenges, including interoperability, organisational barriers, and technology adoption issues [16,18,25]. From an industry perspective, these limitations continue to affect the effective use of VR-BIM during project review and coordination. From a research perspective, despite the growing interest in immersive technologies, the literature still lacks structured frameworks that integrate immersive BIM environments with project information, stakeholder interaction, decision-making, and workflow optimisation. Furthermore, few studies have proposed such frameworks with preliminary evaluation prior to practical implementation.

To address this gap, this study aims to develop a structured VR-BIM integration framework for construction project review, decision-making, and workflow optimisation. The framework integrates digital project information, immersive visualisation, stakeholder interaction, and decision-making within a unified structure. It was preliminarily evaluated through an expert survey involving experienced construction professionals to assess its clarity and practical applicability. This study contributes a structured VR-BIM integration framework with a preliminary expert evaluation, providing a foundation for future empirical validation and implementation in construction projects.

2. Background Study

The proposed VR-BIM integration framework was based on a review of literature related to BIM, VR, construction coordination, and workflow optimisation. The review examined BIM and VR-based approaches used in project review and coordination, together with stakeholder interaction and immersive review processes. Particular attention was given to recurring themes, research gaps, and practical challenges. Framework development was also informed by discussions with construction professionals.

The analysis also considered barriers to VR-BIM adoption, including interoperability constraints, organisational readiness, implementation effort, and user acceptance [16]. These considerations ensured the framework reflected reported challenges while remaining relevant to construction practice.

Selected representative VR-BIM studies are summarised in Table 1 to illustrate their primary contributions and research gaps. Together with the broader literature, these studies provide key insights into VR-BIM research and establish the rationale for the proposed framework.

Table 1
Key VR-BIM studies and highlighted research gaps

Study	Primary Contribution	Highlighted Research Gaps
(Zaker & Coloma, 2018)	Demonstrated the integration of BIM-VR for design review and project collaboration within a BIM-enabled workflow.	Need for practical and affordable BIM-VR implementation approaches.
(Safikhani et al., 2022)	Provided a comprehensive review of BIM-VR applications across multiple AEC domains.	User experience and interaction design require further investigation in BIM-VR.
(Prabhakaran et al., 2022)	Identified technical, organisational, and implementation challenges affecting immersive technology adoption in construction.	Limited understanding of how immersive technologies can be effectively integrated into construction workflows.
(Astaneh Asl & Dossick, 2022)	Evaluated collaborative 3D coordination processes by comparing immersive VR and traditional BIM environments for remote teams.	Limited evidence on decision-making and workflow outcomes in collaborative VR-BIM environments.
(Balin et al., 2023)	Reviewed immersive BIM applications supporting collaborative AEC processes and discussed future research directions.	Lack of integrated BIM–immersive collaboration frameworks and limited empirical validation of decision-making applications.
(Liu et al., 2023)	Examined research trends, development patterns, and emerging directions of BIM and immersive technologies.	Lack of structured frameworks linking immersive technologies with BIM processes.

(Johansson & Roupé, 2024)	Investigated real-world BIM-VR implementations in construction projects and documented practical applications.	Limited evidence of VR-BIM implementation in construction workflows.
(Van et al., 2025)	Identified socio-technical criteria influencing BIM and immersive technology integration in building projects.	Lack of standardized methodologies for BIM-immersive technology integration.

Collectively, the studies summarised in Table 1 show that VR-BIM research has primarily focused on specific applications such as design review, visualisation, collaboration, and stakeholder engagement [13,16,26]. While these studies have reported promising outcomes, relatively limited attention has been given to developing structured frameworks that integrate digital project information, immersive review, stakeholder interaction, decision-making, and workflow optimisation within a unified process. Furthermore, few studies have proposed such frameworks together with a preliminary expert evaluation before implementation. These observations formed the basis for the proposed VR-BIM integration framework developed in this study.

3. Framework Development

This study adopted a conceptual framework development approach followed by a preliminary expert evaluation survey. The framework was developed through four stages: literature analysis, gap identification, concept synthesis, and framework structuring, supported by industry discussions. First, the reviewed literature was analysed to establish how BIM and immersive technologies are currently applied during construction reviews and coordination. Second, research gaps were identified by comparing research objectives, methods, and outcomes across studies. Third, recurring concepts and functional requirements were synthesised, forming the basis for the framework components. Finally, these components were organised into a structured multi-layer framework reflecting the progression from project information to review interaction, decision-making, and workflow outcomes. The overall development process is presented in Figure 1. The resulting framework was intended as a conceptual structure for preliminary evaluation rather than a fully validated implementation model.

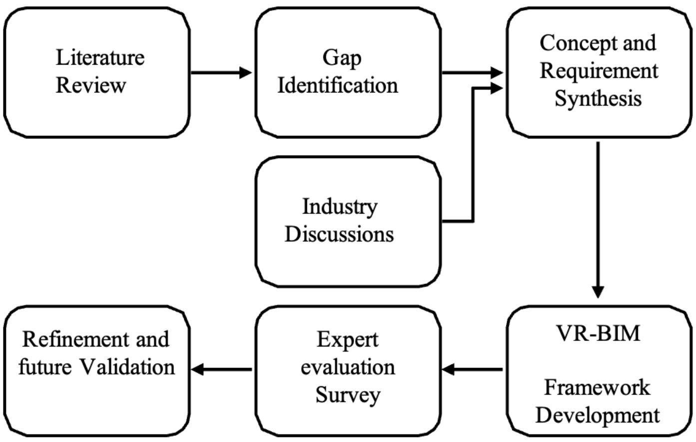

Fig. 1. Framework development process incorporating literature review, industry discussions, and expert evaluation

Following framework development, a preliminary evaluation was conducted through an expert survey involving construction professionals in the United Arab Emirates. Participants were selected using purposive sampling based on their direct experience in project review, coordination, construction management activities, and the application of digital technologies within construction projects. Respondents represented a range of professional roles, including project management, engineering, consultancy, BIM-related functions, and construction coordination activities. This approach ensured that feedback was obtained from practitioners familiar with both BIM-based processes and the practical realities of project delivery.

The survey instrument was designed to assess the framework's clarity, logical structure, completeness, perceived usefulness, and practicality. The questionnaire items were derived from the proposed framework and the reviewed VR-BIM literature to ensure alignment with the study objectives. The internal consistency of the questionnaire was assessed using Cronbach's alpha (α = 0.973). This indicates a high level of internal consistency among the questionnaire items [9]. Participants were first provided with a graphical overview of the framework to establish a common reference point. They were then asked to respond to a series of evaluation statements using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Open-ended questions were included to capture qualitative observations, concerns, and suggestions that could not be fully expressed through scaled responses.

In total, 31 valid responses were received from professionals representing consultancy practices, contracting organisations, client bodies, developers, and government authorities. As this study involved a preliminary expert evaluation, the emphasis was on obtaining informed professional judgement rather than achieving statistical representation. Given their industry experience, the respondents were well positioned to comment on the framework's relevance to project review and coordination activities. Quantitative data were analysed using descriptive statistics to summarise respondent characteristics and calculate mean scores for each evaluation criterion. Qualitative feedback was reviewed manually and grouped into recurring themes related to perceived strengths, implementation challenges, and suggested framework improvements. These themes were subsequently interpreted alongside the quantitative findings and compared with observations reported in the existing VR-BIM literature.

4. Results and Discussion

This section presents the proposed VR-BIM integration framework and the findings obtained from its preliminary evaluation. The framework is first described in terms of its conceptual structure and underlying rationale. Subsequently, the results of the expert evaluation survey are presented and discussed, followed by an examination of qualitative feedback and comparison with observations reported in previous studies.

4.1 VR-BIM Integration Framework (Concept and Structure)

Figure 2 presents the proposed VR-BIM integration framework developed from the literature review and gap analysis. The framework consists of six interconnected layers linking digital project information, immersive visualisation, stakeholder interaction, coordination, and project performance outcomes.

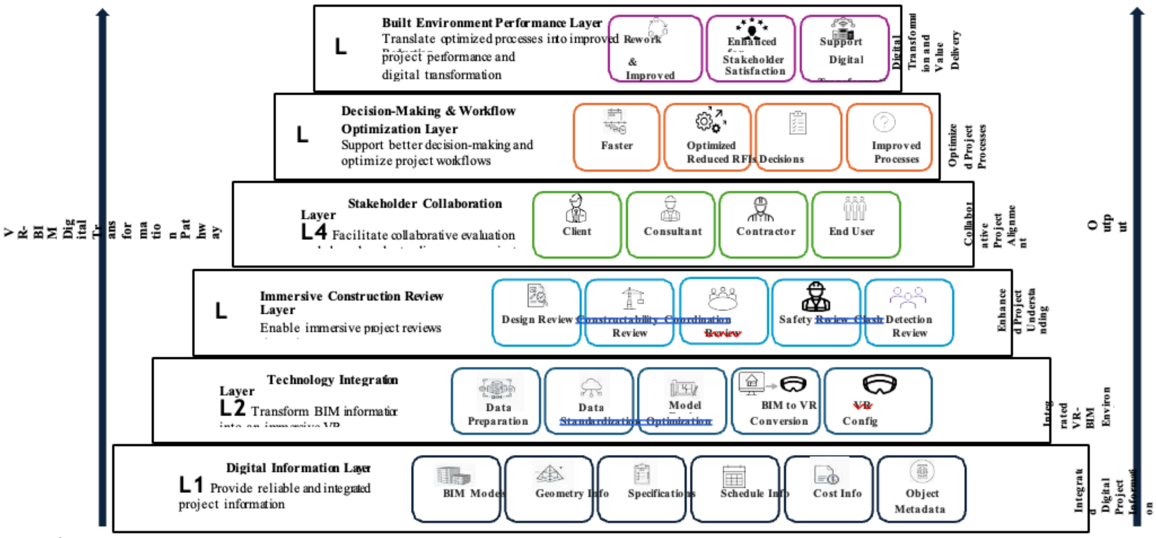

Fig. 2. Proposed VR-BIM integration framework for decision-making and workflow optimisation in construction projects

The framework proposes that integrating these capabilities improves decision-making, coordination, workflow optimisation, and project performance. The six layers describe the progression from digital project information to broader project outcomes. Rather than treating VR as an isolated technology, the framework positions it within a sequence of activities in which project information is interpreted, discussed, evaluated, and translated into decisions. Each layer performs a distinct role while remaining dependent on the preceding layer.

At the foundation of the framework is the Digital Information Layer (L1). Construction reviews depend on reliable project information. BIM models, specifications, schedules, cost data, and object metadata form the starting point of the framework. These information sources provide the basis for project evaluation. Incomplete or inconsistent data may compromise subsequent review activities.

The Technology Integration Layer (L2) serves as the connection between BIM information and the immersive review environment. Before project information can be explored in VR, several preparatory steps are required, including data preparation, standardisation, model optimisation, BIM-to-VR conversion, and virtual environment configuration. These activities influence the usability of immersive review environments. The output is an integrated VR-BIM environment supporting review activities.

The Immersive Construction Review Layer (L3) represents the point at which project information becomes actively explored and evaluated. Design, constructability, coordination, and safety reviews together with clash detection represent common review activities. Within an immersive environment, these activities can be undertaken while maintaining a stronger perception of scale, space, and spatial relationships than is typically possible through conventional screen-based reviews. This layer supports clear understanding of project conditions and potential issues.

Understanding alone is rarely sufficient to influence project outcomes. Construction decisions normally involve multiple parties with different responsibilities and priorities. For this reason, the framework includes a dedicated Stakeholder Collaboration Layer (L4). Clients, consultants, contractors, and end users are positioned within this layer to emphasise the collaborative nature of project reviews. Improved access to project information and immersive visualisation may facilitate more productive discussions among stakeholders.

The benefits generated through review and collaboration activities are expected to influence project decision-making and workflow management. This relationship is represented by the Decision-

Making and Workflow Optimisation Layer (L5). The layer focuses on outcomes such as faster decisions, improved decision quality, reduced requests for information, and more efficient project processes. These outcomes support better coordination and project efficiency.

The final layer extends beyond individual review activities and considers their broader implications for project delivery. The Built Environment Performance Layer (L6) captures outcomes such as reduced rework, improved project performance, support for digital transformation, and stakeholder satisfaction. These outcomes are not presented as guaranteed results. Instead, they represent the intended direction of improvement when the preceding layers operate effectively and in combination. In this respect, digital transformation is viewed as an outcome of better use of project information, improved collaboration, and informed decision-making rather than a technological objective.

Overall, the framework follows a progression in which project information is transformed into understanding, understanding supports collaboration, collaboration contributes to decision-making, and improved decisions influence project performance. By linking these stages within a single structure, the framework provides a conceptual basis for examining how VR-BIM integration may contribute to construction project reviews and workflow improvement. Future empirical studies are needed to validate these relationships in construction projects.

4.2 Survey Results (Quantitative Evaluation of Framework)

A total of 31 valid responses were obtained from construction professionals representing different stakeholder groups within the construction sector. As shown in Table 2, consultants formed the largest respondent group (35.5%), followed by contractors (29.0%) and clients (22.6%). Government authorities and developers each represented 6.5% of the sample. This distribution provided perspectives from organisations involved in project planning, delivery, governance, and oversight, allowing the framework to be evaluated from multiple industry viewpoints.

Table 2
Respondent profile

Organisation Type	Frequency	Percentage (%)
Consultant	11	35.5
Contractor	9	29.0
Client	7	22.6
Government	2	6.5
Developer	2	6.5
Total	31	100.0

The responses indicate generally favourable perceptions of the framework. Mean scores for all criteria exceeded 3.5 on the five-point scale, indicating positive evaluations across all criteria as shown in Table 3.

Table 3
Framework evaluation results

Evaluation Criterion	Mean	SD
Framework is clear and easy to understand	3.90	0.79
Framework components are logically organised	3.90	0.70
Framework adequately represents BIM-VR integration	3.74	0.73
Improves project understanding among stakeholders	4.06	0.89
Supports informed decision-making during reviews	4.00	0.86

Improves communication among stakeholders	3.97	0.84
Improves multidisciplinary coordination	4.00	0.86
Reduces misunderstandings during project reviews	3.97	0.84
Contributes to reducing design revisions and rework	3.90	0.83
Improves workflow efficiency	3.97	0.84
Practical for implementation in construction projects	3.68	0.94
Supports digital transformation initiatives	3.84	0.82
Support for further development and implementation	3.94	0.81
Improves decision quality	3.97	0.95
Reduces review time	3.94	0.93

All evaluation criteria scored above the neutral value of 3.0, indicating generally positive perceptions of the framework. The highest mean score was recorded for improving project understanding among stakeholders (4.06). This outcome is noteworthy because difficulties in interpreting project information are frequently cited as a source of coordination problems [13,28]. Respondents recognised the value of immersive environments in helping participants better understand project conditions and design intent.

Scores relating to decision-making (4.00), multidisciplinary coordination (4.00), communication (3.97), decision quality (3.97), workflow efficiency (3.97), and reducing misunderstandings (3.97) showed minimal variation. Although the differences were small, respondents viewed the framework as more than a visualisation tool. Respondents viewed the framework as supporting broader coordination and review functions beyond visualisation.

Support for further development and implementation also received a positive evaluation (3.94), despite respondents assessing a conceptual framework rather than a fully implemented system. This suggests that the framework structure and relationships between its layers are relevant to contemporary construction practice. The lowest mean score related to practical implementation in construction projects (3.68). While still above the neutral point, this result reflects a degree of caution among respondents. Comments received through the survey indicate that implementation challenges remain a concern. These include investment in hardware and software, integration with existing BIM processes, staff training requirements, and varying levels of organisational readiness. Such concerns are consistent with the realities of technology adoption in the construction industry, where operational constraints often influence the pace of implementation [18,25].

Digital transformation was also viewed positively, with a mean score of 3.84. Although not among the highest-rated criteria, the result indicates recognition that immersive technologies may contribute to ongoing digitalisation efforts within the sector. The score suggests measured optimism rather than unconditional acceptance, reflecting the current maturity of VR adoption across the industry. Overall, the findings provide initial support for the proposed framework. The strongest responses were associated with understanding, coordination, communication, and decision-related activities, while implementation issues attracted greater caution. These findings suggest that respondents recognised the framework's potential while remaining mindful of the practical considerations of introducing new digital technologies.

4.3 Expert Feedback and Comparison with Prior Studies

In addition to the quantitative evaluation, respondents were invited to provide comments regarding the strengths, implementation challenges, and potential improvements associated with the proposed framework. Although the comments varied in depth and focus, several common observations emerged. Many respondents highlighted improvements in project understanding and communication. They noted that immersive visualisation could help stakeholders better interpret project information, identify coordination issues earlier, and develop a shared understanding of project requirements. Several participants highlighted the ability of VR environments to improve the visualisation of design conflicts and support clearer discussions. Others emphasised that immersive reviews may help decision-makers understand complex project conditions that are difficult to communicate through conventional drawings or desktop-based model reviews. These observations are consistent with the quantitative findings, where project understanding, decision-making, communication, and coordination received some of the highest mean scores.

Implementation emerged as a recurring concern across many responses. While respondents generally viewed the framework positively, many acknowledged practical barriers that could influence adoption. Common concerns included the cost of hardware and software, staff training requirements, integration with existing BIM workflows, and organisational readiness. Several respondents also referred to the need for stronger awareness of immersive technologies within the construction sector. These comments help explain why implementation practicality received the lowest mean score among the evaluation criteria. Rather than questioning the value of the framework, respondents appeared to be highlighting challenges commonly associated with the introduction of new digital technologies into established project environments.

The comments also pointed to several areas where the framework could be further developed. Multi-user collaboration within the same virtual environment was repeatedly identified as a desirable enhancement. Other recommendations included improving interoperability with different BIM platforms, incorporating user feedback mechanisms, introducing performance indicators, and providing structured training programmes to support implementation. Some respondents additionally suggested incorporating risk management considerations and more explicit performance measurement capabilities. These recommendations suggest that practitioners view the framework as a useful foundation while recognising opportunities for refinement.

Several observations are consistent with earlier VR-BIM studies. Safikhani *et al*., [21] highlighted the ability of immersive technologies to improve visualisation and stakeholder understanding, while Astaneh Asl and Dossick [2] reported benefits associated with collaborative review environments. The responses in this study point in a similar direction, particularly regarding communication, coordination, and decision-making. At the same time, the implementation concerns identified by respondents reflect challenges previously reported by Prabhakaran *et al*., [18] and Van *et al*., [25], particularly those associated with adoption barriers, integration complexity, organisational readiness, and technology deployment.

The feedback was not limited to visualisation-related advantages. Many comments linked immersive review environments to broader project outcomes, including improved coordination, clearer communication, and more informed decision-making. This perspective is consistent with the underlying premise of the proposed framework, which positions VR-BIM integration as part of a wider coordination and workflow process rather than merely a visualisation tool. These findings suggest that the value of VR-BIM extends beyond immersive visualisation. The proposed framework links digital project information, stakeholder interaction, decision-making, and workflow processes within a single structure, supporting a more integrated approach to construction project review and coordination. The practical concerns raised by respondents also highlight the need for further empirical validation under real project conditions. From a practical perspective, the framework provides construction managers, BIM specialists, consultants, and other stakeholders with a structured approach for integrating immersive technologies into project review and coordination. Although further validation is required, the preliminary findings indicate that the framework could support more consistent communication, informed decision-making, and workflow management in construction projects.

5. Conclusion

This study presented a VR-BIM integration framework intended to support project review, stakeholder interaction, decision-making, and workflow optimisation. Instead of treating VR as only a visualisation tool, the framework positions it within a sequence of activities that link project information, coordination, decision-making, and project performance outcomes.

The results should be interpreted within the context of the limitations of the study. The framework was evaluated through an expert survey and not in an active project environment. Furthermore, the survey was conducted with a relatively small number of professionals working in the United Arab Emirates. These participants offered informed industry insights, but the findings should not be taken as representative of the broader construction industry without further research.

The proposed framework represents an early outcome of an ongoing research project and will be further validated through experimental studies involving real construction project scenarios. Future studies will examine whether the perceived benefits translate into measurable improvements in coordination effectiveness, review efficiency, decision quality, and workflow performance.

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References

[1] Alsharef, Abdullah, Anto Ovid, S. M. Jamil Uddin, and Alex Albert. "Biggest challenges facing the construction industry." In *Construction Research Congress 2024*, pp. 652-660. 2024 https://doi.org/10.1061/9780784485286.065

[2] Astaneh Asl, Bita, and Carrie Sturts Dossick. "Immersive VR versus BIM for AEC team collaboration in remote 3D coordination processes." *Buildings* 12, no. 10 (2022): 1548. https://doi.org/10.3390/buildings12101548

[3] Azhar, Salman. "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry." *Leadership and management in engineering* 11, no. 3 (2011): 241-252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

[4] Bagasi, Omar, Nawari O. Nawari, and Adel Alsaffar. "BIM and AI in Early Design Stage: Advancing Architect–Client Communication." *Buildings* 15, no. 12 (2025): 1977. https://doi.org/10.3390/buildings15121977

[5] Balin, Simone, Cecilia M. Bolognesi, and Paolo Borin. "Integration of immersive approaches for collaborative processes with building information modeling (BIM) methodology for the AEC industry: An analysis of the current state and future challenges." In *Virtual Worlds*, vol. 2, no. 4, pp. 374-395. MDPI, 2023. https://doi.org/10.3390/virtualworlds2040022

[6] Daoud, Ahmed Osama, Ayodeji Emmanuel Oke, Atul Kumar Singh, Ibukun O. Famakin, Khaled Mahmoud Abdel Aziz, and Taiwo Matthew Olayemi. "Exploring the building information modelling benefits for sustainable construction using PLS-SEM." *Scientific Reports* 15, no. 1 (2025): 35781 https://doi.org/10.1038/s41598-025-14020-0

[7] Eastman, Charles M. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons, 2011.

[8] Getuli, Vito, Pietro Capone, Alessandro Bruttini, and Shabtai Isaac. "BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach." *Automation in construction* 114 (2020): 103160. https://doi.org/10.1016/j.autcon.2020.103160

[9] Hair, Joseph, and Abdullah Alamer. "Partial Least Squares Structural Equation Modeling (PLS-SEM) in second language and education research: Guidelines using an applied example." *Research methods in applied linguistics* 1, no. 3 (2022): 100027. https://doi.org/10.1016/j.rmal.2022.100027

[10] Hwang, Bon-Gang, Stephen R. Thomas, Carl T. Haas, and Carlos H. Caldas. "Measuring the impact of rework on construction cost performance." *Journal of construction engineering and management* 135, no. 3 (2009): 187-198.https://doi.org/10.1061/(ASCE)0733-9364(2009)135:3(187)

[11] Johansson, Mikael, and Mattias Roupé. "Real-world applications of BIM and immersive VR in construction." Automation in Construction 158 (2024): 105233. https://doi.org/10.1016/j.autcon.2023.105233

[12] Khahro, Shabir Hussain, Haseeb Haleem Shaikh, Yasmin Zainun Noor, Basel Sultan, and Qasim Hussain Khahro. "Delay in decision-making affecting construction projects: a sustainable decision-making model for mega projects." *Sustainability* 15, no. 7 (2023): 5872. https://doi.org/10.3390/su15075872

[13] Khan, Ayaz, Samad Sepasgozar, Tingting Liu, and Rongrong Yu. "Integration of BIM and immersive technologies for AEC: A scientometric-SWOT analysis and critical content review." *Buildings* 11, no. 3 (2021): 126. https://doi.org/10.3390/buildings11030126

[14] Liu, Zhen, Shiqi Gong, Zhiya Tan, and Peter Demian. "Immersive technologies-driven building information modeling (BIM) in the context of metaverse." *Buildings* 13, no. 6 (2023): 1559.https://doi.org/10.3390/buildings13061559

[15] Love, Peter ED, Jim Smith, Fran Ackermann, and Zahir Irani. "Making sense of rework and its unintended consequence in projects: The emergence of uncomfortable knowledge." *International journal of project management* 37, no. 3 (2019): 501-516. https://doi.org/10.1016/j.ijproman.2019.02.004

[16] Lyu, Fujia, Grant Mills, and Weiwei Chen. "Enhancing Collaboration in the Project Lifecycle: Addressing BIM-based VR Challenges and Barriers." In *Proceedings of the European Conference on Computing in Construction*. European Council on Computing in Construction (EC³), 2025. https://doi.org/10.35490/EC3.2025.357

[17] Mahamid, Ibrahim. "Rework investigation in residential building projects: Cost, factors and effects." *International Review of Applied Sciences and Engineering* 15, no. 1 (2024): 116-122. https://doi.org/10.1556/1848.2023.00694

[18] Prabhakaran, Abhinesh, Abdul-Majeed Mahamadu, and Lamine Mahdjoubi. "Understanding the challenges of immersive technology use in the architecture and construction industry: A systematic review." *Automation in Construction* 137 (2022): 104228. https://doi.org/10.1016/j.autcon.2022.104228

[19] Premakumara, Amila, and Chandana Siriwardana. "A comprehensive approach for assessing the causes of low productivity in the construction sector: a systematic categorization and ranking using Pareto and Fuzzy analysis." *Construction Management and Economics* 43, no. 1 (2025): 40-58. https://doi.org/10.1080/01446193.2024.2377712

[20] Rashidi, Ali, Amjad Mohammed Maalim, Laura Gutierrez-Bucheli, Duncan Maxwell, and Mehrdad Arashpour. "Evaluating the effectiveness of BIM-based virtual reality for coordinating the design disciplines in a building renovation project." In *IOP Conference Series: Earth and Environmental Science*, vol. 1101, no. 3, p. 032019. IOP Publishing, 2022. https://doi.org/10.1088/1755-1315/1101/3/032019

[21] Safikhani, Saeed, Stephan Keller, Gerald Schweiger, and Johanna Pirker. "Immersive virtual reality for extending the potential of building information modeling in architecture, engineering, and construction sector: systematic review." *International Journal of Digital Earth* 15, no. 1 (2022): 503-526. https://doi.org/10.1080/17538947.2022.2038291

[22] Sardi-Barzallo, Juan, and Volker Coors. "From Mixed Reality to BIM: A Workflow for the Integration of Immersive Technologies at Architectural Design Process." In *Proceedings of the 30th International Conference on 3D Web Technology*, pp. 1-9. 2025. https://doi.org/10.1145/3746237.3746309

[23] Succar, Bilal. "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in construction* 18, no. 3 (2009): 357-375.https://doi.org/10.1016/j.autcon.2008.10.003

[24] Tariq, Junaid, and S. Shujaa Safdar Gardezi. "Study the delays and conflicts for construction projects and their mutual relationship: A review." *Ain Shams Engineering Journal* 14, no. 1 (2023): 101815.https://doi.org/10.1016/j.asej.2022.101815

[25] Pham, Van Bao, Shek Pui Peter Wong, and Behzad Abbasnejad. "A systematic review of criteria influencing the integration of BIM and Immersive Technology in building projects." (2025). https://doi.org/10.36680/j.itcon.2025.011

[26] Wijerathna, Ashirwada, Srinath Perera, Samudaya Nanayakkara, and Sisi Zlatanova. "Developing a workflow for transforming BIM models into immersive virtual reality experiences." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives* 48, no. 4 (2024): 485-492. https://doi.org/10.5194/isprs-archives-XLVIII-4-2024-485-2024

[28] Xiang, Yiming, Abdul-Majeed Mahamadu, and Laura Florez-Perez. "Engineering information format utilisation across building design stages: An exploration of BIM applicability in China." *Journal of Building Engineering* 95 (2024): 110030. https://doi.org/10.1016/j.jobe.2024.110030

[29] Yap, Jeffrey Boon Hui, and Shi Min Tan. "Investigating rework: insights from the Malaysian construction industry." *ASM Science Journal* 14 (2021): 1-9. https://doi.org/10.32802/asmscj.2020.636

[30] Zaker, Reza, and Eloi Coloma. "Virtual reality-integrated workflow in BIM-enabled projects collaboration and design review: a case study." *Visualization in Engineering* 6, no. 1 (2018): 4.https://doi.org/10.1186/s40327-018-0065-6