A SEMI-AUTOMATED BIM-TO-VR WORKFLOW FOR TEACHING: ROBUST MODEL REVIEW IN CAVE AND HMD ENVIRONMENTS

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Abstract

Current BIM-to-VR approaches enable immersive visualization of buildings but often require extensive manual preprocessing and rely on rigid modeling conventions, limiting scalability and reuse. This paper presents a semi-automated BIM-to-VR workflow that enables immersive interaction with building data derived from Autodesk Revit in a VR environment implemented in Unity. The method automatically parses model hierarchies, derives building-level and component groupings, assigns colliders, and enables group-based visibility control and navigation without additional preprocessing. The workflow is demonstrated in both room-scale VR and head-mounted display setups and validated in teaching scenarios, showing reduced preparation effort and robust reuse across VR platforms.

Introduction

The architecture, engineering, and construction (AEC) industry has undergone a gradual transition from two-dimensional drafting toward three-dimensional digital modeling, with Building Information Modeling (BIM) becoming a core method for representing geometry and technical information across the building lifecycle (Sacks et al., 2018). However, interacting with complex BIM data through conventional desktop-based tools can be cognitively demanding, often limiting spatial understanding and collaborative discussion at building scale (Whyte, 2003). Immersive Virtual Reality (VR) has therefore gained attention as a complementary medium that enables intuitive exploration of BIM models, enhancing spatial cognition and improving the comprehension of architectural spaces compared to traditional visualization approaches (Samarasinghe et al., 2019).

In addition to improved visualization, VR systems support real-time interaction with building models. This capability helps designers and stakeholders identify design issues, respond to feedback, and refine solutions at early stages, thereby reducing the risk of costly changes later in the project lifecycle (Kamari et al., 2021). Due to these advantages, VR has been increasingly applied across different stages of the building lifecycle to enhance collaboration, decision-making, and design communication. Several studies have demonstrated the value of VR in stakeholder-driven sustainable design decision-making. For example, Atwa et al. (2019) used VR to collect feedback from users and experts during the development of sustainable landscape design principles for green business parks, enabling more informed and inclusive decision-making processes. Similarly, Tseng and Giau (2022) applied VR as an assessment tool for elderly housing, suggesting that immersive VR experiences offer a more realistic sense of presence and improved spatial understanding prior to occupancy.

In parallel with professional practice, significant efforts have been made to integrate BIM into AEC education curricula worldwide (Arundhati et al., 2013; Sacks and Pikas, 2013). BIM-based models and associated databases offer an enhanced educational platform by presenting complex construction information in a visual and accessible format (Clevenger et al., 2012). In particular, BIM's 4D capabilities enable students to better understand construction sequencing and assembly processes through animated simulations (Gledson and Dawson, 2017). In parallel, immersive technologies such as VR have been increasingly adopted in education, including gamification, game-enhanced learning, and experiential learning environments (Shavinina, 2013). Research on VR in education has increased substantially over the past two decades, with studies consistently reporting improved student understanding through direct interaction within realistic environments (Blazauskas et al., 2017).

Nevertheless, prior research emphasizes that VR applications must be grounded in appropriate pedagogical frameworks and learning theories to ensure alignment with educational objectives (Liu et al., 2017). This aligns with core Human-Data Interaction (HDI) principles, which suggest that for building data to be effectively utilized, the workflow must ensure legibility—making complex data understandable to the human observer—and provide the user with sufficient agency to control and customize the review process (Davila-Delgado et al., 2024; Kassem and Kifokeris, 2025).

Recent studies have specifically explored the integration of BIM and VR for AEC education. Elgewely et al. (2021) developed a BIM-integrated VR platform for construction detailing education and demonstrated that immersive, collaborative interaction with BIM models significantly improved students' engagement, motivation, and learning outcomes compared to traditional paper-based study. Similarly, Sanchez et al. (2021) reported on an intuitive and accessible BIM–VR educational framework embedded within an AEC course curriculum. Their work illustrated how BIM–VR can be leveraged as a data-rich learning infrastructure to support complex design understanding, teamwork, remote collaboration, and client-oriented project presentation, reinforcing the value of BIM–VR as an effective educational medium in higher education.

Despite these promising results, Radianti et al. (2020), in a systematic mapping study of immersive VR applications in higher education, concluded that many VR-based educational systems remain experimental, lack grounding in learning theories, and focus primarily on usability rather than learning outcomes. Nevertheless, their findings confirm the strong potential of immersive VR as an effective and affordable pedagogical tool in university-level education.

In response to the limitations identified in existing BIM–VR applications, this paper presents a semi-automated BIM-to-VR workflow that enables immersive interaction with building data while minimizing manual preprocessing and avoiding reliance on proprietary VR middleware. The approach relies on hierarchy-based parsing of BIM-derived models after export, without requiring additional naming conventions or model-specific preparation. Building structures and component groupings are derived automatically from the existing model hierarchy, with interaction logic applied at the group level rather than per object. The workflow supports group-based visibility control, access to material information, automatic collider assignment, and navigation, and is robust to variations in model quality.

System Capabilities

The proposed workflow enables the immersive exploration of BIM data in VR environments, focusing on minimal manual preprocessing and broad accessibility. The system operates independently of proprietary VR middleware and requires only a standard export in the FBX format—the primary geometry exchange format utilized by Unity—from BIM authoring tools such as Autodesk Revit. Supporting both room-scale immersive

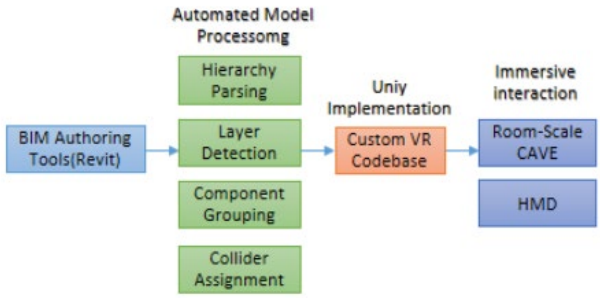

Figure 1: BIM-to-VR workflow

CAVE systems and personal head-mounted displays (HMDs), the implementation ensures a consistent user experience across varied hardware configurations. Figure 1 provides an overview of the processing stages, illustrating how the workflow enhances the legibility of complex building data—a core HDI principle—by ensuring that model hierarchies are automatically structured into a format that is understandable to non-expert users.

Upon importing a BIM-derived model, the system performs several automated operations to prepare it for interaction. Hierarchy parsing traverses the FBX structure to identify structural groupings and assemblies, detecting vertical levels and horizontal component clusters based on geometry distribution and node organization. Layer detection then infers building levels using geometry-aware height clustering, producing an ordered sequence of floors without relying on manual naming conventions or semantic annotations. Component grouping organizes subcomponents within each layer according to their hierarchical position, typically corresponding to major systems such as walls, slabs, or equipment assemblies, while collider assignment automatically equips mesh components with physics colliders to enable navigation without manual setup.

Building on this automated structuring, the interaction logic supports intuitive exploration, preserving spatial continuity through continuous, grounded movement. To ensure the system remains accessible to novice users,

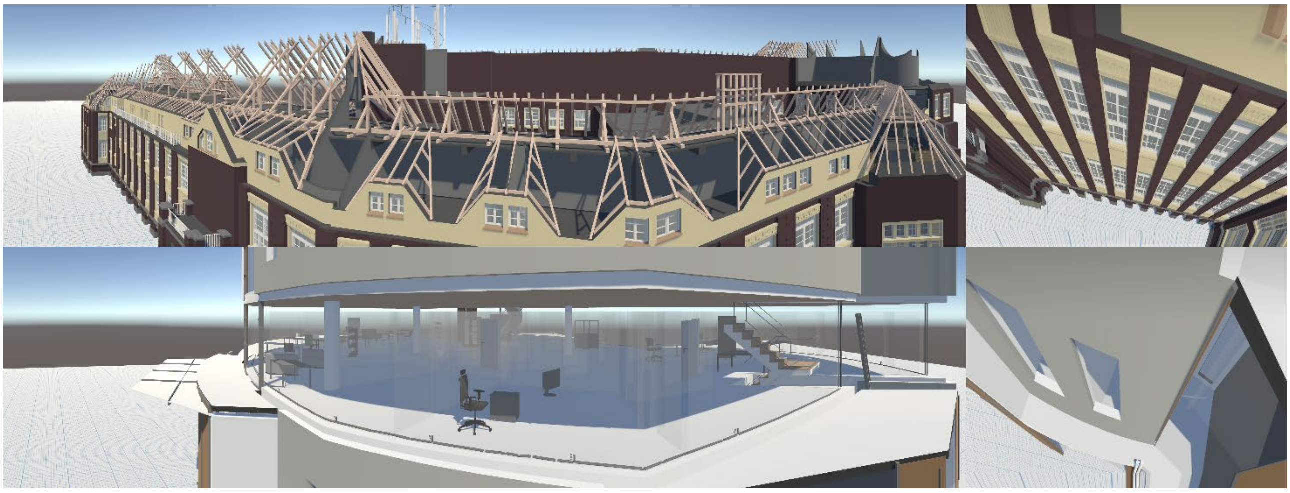

Figure 2: Immersive BIM model exploration in a room-scale VR (CAVE) environment

Table 1: Comparison of BIM-to-VR workflows for educational and exploratory use

	Proposed Workflow	Unity Reflect	Twinmotion
Required Export	fbx	Direct link	Datasmith exporter
Group/Layer Automation	yes	limited	limited
Interaction flexibility	high	low	moderate
CAVE support	yes	limited	limited
Primary use	Education&discussion	presentation	visualization

navigation is mapped to a standard Xbox controller. This choice of input device provides a familiar interface for students, allowing them to move through the building model with minimal technical training. The system's unified interaction logic ensures that the controller functions identically across both the room-scale CAVE and HMD-based setups, providing a consistent sense of agency as users choose their own paths through the digital environment.

To contextualize the proposed approach within the broader landscape of BIM-to-VR solutions, Table 1 compares the workflow with commonly used commercial and engine-based pipelines from the perspective of educational deployment. The comparison highlights differences in required preprocessing effort, dependence on proprietary middleware, and interaction flexibility.

Methodology

This study adopted an experimental research methodology conducted through a field-based teaching deployment to evaluate the real-world utility of the semi-automated BIM-to-VR workflow. The research was designed as a single-cohort study without a control group, focusing on the use of BIM models authored by participants in Autodesk Revit to isolate the specific impact of the automated processing from the general cognitive benefits of VR visualization. The deployment involved 40 students from architecture and engineering programs, organized into 11 groups of 5–6 participants. To facilitate the technical onboarding and ensure consistent system usage, the students were guided by one expert facilitator.

The VR application was deployed exclusively in a room-scale, multi-wall CAVE system to support shared immersive experiences. To facilitate navigation within this space, each student group utilized an Xbox controller as their primary interaction tool. During the standardized 30–45 minute introductory session, the expert facilitator trained the 40 students on how to use the controller to traverse the model, toggle layer visibility, and perform "peeling" interactions. By using a familiar consumer-grade controller, the study aimed to reduce the cognitive load on participants, allowing them to focus on the architectural review tasks rather than the mechanics of navigation.

The study is grounded in Human-Data Interaction (HDI) principles, specifically focusing on how the workflow enhances the legibility of complex building data and provides users with the agency to control and customize their review process. To emphasize educational application rather than tool demonstration, the VR sessions were structured as model-based review tasks aligned with established BIM learning objectives:

- **Spatial understanding and scale:** Participants explored their own partial BIM models at a 1:1 scale to assess proportions, spatial relationships, sightlines, and potential bottlenecks. This task leveraged VR's documented strengths in conveying scale and spatial detail, which are often lost on 2D screens.
- **Structural and system understanding:** Layer- and group-based visibility controls, including the progressive "peeling" interaction, were used to analyze complex relationships between internal building systems, such as the coordination between structural slabs and MEP equipment.
- **Data reflection and model quality:** Students performed material plausibility checks and metadata inspections to identify inconsistencies, such as missing or implausible material assignments. This process was designed to foster trust in the digital model by allowing students to verify informational accuracy directly within the 3D environment.
- **Collaboration:** Teams engaged in group-based discussion and joint critique of model segments directly within the immersive environment. This supported collective reasoning and peer-based feedback, as the shared viewpoint in the CAVE enabled members to ground their dialogue in the same visual evidence.

To reduce entry barriers and ensure consistent use across the 11 groups, a standardized training procedure was implemented. At the beginning of the study, participants attended an introductory session lasting approximately **30–45 minutes**, covering essential aspects of VR usage, including safety considerations, navigation principles, group-based visibility controls, and the use of material plausibility checks. Following this introduction, student groups were granted repeated, independent access to the CAVE system over a period of **2–3 weeks**. During this deployment phase, participants independently imported their own BIM models, performed the assigned review tasks, and documented their observations and discussion outcomes.

Data collection followed a mixed-methods approach, utilizing a structured questionnaire (n=40) and short reflective interviews to capture both measurable perceptions and contextualized user experiences. Quantitative data from Likert-scale and categorical items were analyzed using descriptive statistics, including frequencies and percentages, to measure system usability and spatial comprehension. Qualitative data from open-ended questions were analyzed using thematic analysis following Braun and Clarke's inductive approach to identify recurring themes in the users' experiences. This rigorous approach allowed the study to distinguish between the inherent effectiveness of VR and the specific performance of the automated BIM-to-VR pipeline.

Discussion and Result Analysis

The evaluation of the system, based on 40 completed questionnaires, indicates high usability and effective pedagogical support despite the participants' limited technical background. As illustrated in Figure 3, which summarizes participants' prior experience with BIM tools, game engines, and VR, the study sample predominantly consisted of novice users. Specifically, nearly half of the participants (47.5%) reported no prior experience with Autodesk Revit, while 95% had no prior exposure to Unity and 87.2% had never used VR before. Despite this limited background, quantitative results indicate overall positive system usability, with 65% of participants expressing a desire to use the system frequently and 56.4% reporting confidence in its operation. While some participants initially faced a learning curve, qualitative feedback suggested these challenges diminished quickly with the guidance of the single expert facilitator who supported the 40 students during their initial onboarding. This suggests that the usability challenges were primarily related to first-time navigation rather than the fundamental design of the automated workflow.

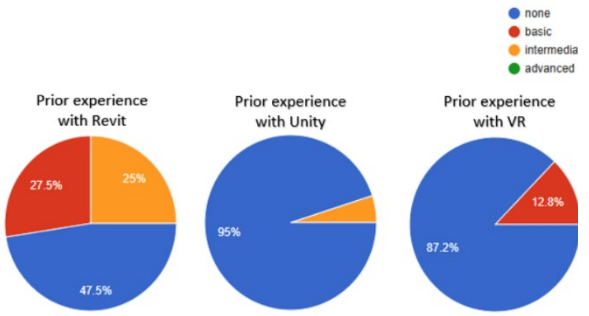

Figure 3: Prior Experience with BIM tools and VR

To address the distinction between general VR effectiveness and the proposed BIM-to-VR workflow, it is important to note that while VR inherently aids spatial reasoning, the automated hierarchy parsing was the specific factor that enabled these results for novice users. Without the semi-automated assignment of colliders and grouping, students would have spent the majority of their time on technical model preparation rather than analytical review. Spatial understanding represented the strongest observed effect, with 74.2% of participants reporting a better grasp of proportions and 61.3% finding spatial problem detection easier in VR than in desktop BIM tools. As illustrated in Figure 4, which displays the quantitative responses to spatial understanding and learning-related items, the results are strongly skewed toward agreement. By reducing technical friction, the workflow allowed participants to focus on high-level cognitive tasks, such as system-level reasoning and collaborative critique, which are often hindered in manual or proprietary pipelines.

From a Human-Data Interaction (HDI) perspective, the use of the Xbox controller was a key factor in promoting user agency and reducing the initial learning curve. Quantitative data showed that 56.4% of participants felt confident using the system, a result that qualitative feedback linked to the familiarity of the controller interface. While 20% of participants initially found navigation challenging, the "game-like" nature of the input device allowed them to overcome these hurdles quickly with the help of the expert guide. This choice of hardware, combined with the automated model preparation, effectively bridged the gap between complex architectural data and the user, ensuring that the legibility of the BIM model was matched by an intuitive means of exploration.

Following this intuitive navigation, the role of the workflow is further reflected in how participants interacted with structured building information. Quantitative results show that 50% of participants found layer and group visibility controls essential for understanding building organization, while 57.5% reported benefits from metadata inspection. The "peeling" interaction provided users with the agency to isolate specific systems, making sense of internal relationships that are typically obscured. Furthermore, the inclusion of material checks fostered a sense of trust, as participants could verify the accuracy of their models in real-time, identifying inconsistencies that were previously invisible in the desktop view.

Ultimately, 75% of participants agreed that the VR experience enhanced their learning compared to traditional methods. By removing the need for manual preparation and empowering students to manipulate data directly, the semi-automated workflow successfully bridged the gap between complex digital twins and human understanding. In addition to individual interaction, collaborative use emerged as a vital dimension, with 70.0% of participants perceiving improved team performance. These results suggest that the workflow is a robust tool for educational deployment, fostering improved individual and team performance while upholding the core HDI principles of empowerment and data transparency.

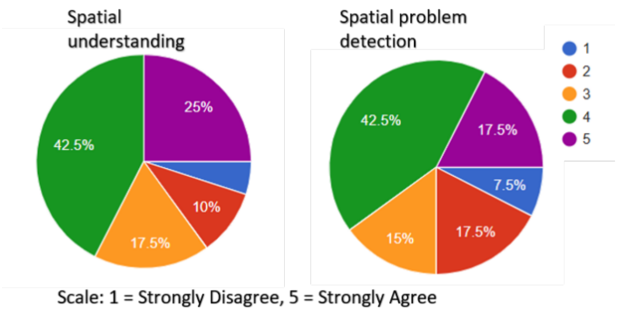

Figure 4: Spatial understanding in VR

Conclusion & Limitations

This research has presented and evaluated a semi-automated BIM-to-VR workflow specifically engineered to bridge the technical gap between complex architectural data and immersive educational review. By implementing an automated pipeline for hierarchy parsing, layer detection, and collider assignment using the FBX format within the Unity engine, the system successfully democratizes access to Virtual Reality for users without game-engine expertise. The field-based deployment, involving 40 students and guided by a single expert facilitator, demonstrates that the workflow is not merely a visualization tool but a functional interface for architectural analysis. A critical finding of this study is the distinction between the inherent cognitive affordances of VR—such as 1:1 scale perception and spatial reasoning—and the operational accessibility provided by the workflow. While the virtual medium provides the "where" for spatial understanding, it is the automated processing of the BIM data that provides the "how," allowing novice users to transition from desktop authoring to immersive critique without the burden of manual model conditioning.

From a theoretical standpoint, this study offers a significant contribution to the framework of Human-Data Interaction (HDI) in the built environment. By structuring interaction at the level of building systems and assemblies rather than granular geometric nodes, the workflow fundamentally enhances the legibility of complex BIM data. This structural clarity allows students to perceive a building not as a collection of meshes, but as a coherent system of floors, walls, and equipment. Furthermore, the provision of visibility controls and the progressive "peeling" interaction grants users a high degree of agency, empowering them to manipulate the digital environment to suit specific analytical tasks. This sense of control is essential for deep learning, as it moves the user from a passive observer to an active investigator of the building's internal logic. Additionally, the integration of material plausibility checks and metadata inspection fosters a vital sense of trust, ensuring that the immersive experience remains a high-fidelity reflection of the underlying engineering data.

The results from the room-scale CAVE deployment underscore the workflow's efficacy in fostering collaborative learning and peer-based critique. With 70% of participants reporting improved team performance and 75% noting an enhanced learning experience, the system proves to be a robust pedagogical aid. While the study identified certain limitations—specifically regarding the initial onboarding curve and the requirement for specialized CAVE infrastructure—the overall success of the deployment suggests that semi-automated BIM-to-VR transitions are a scalable solution for the AEC industry. Future research will focus on extending the system's capabilities to include bi-directional data synchronization, allowing users to annotate and modify BIM data directly within the VR environment. By continuing to refine the interface through the lens of HDI, this work aims to further empower the next generation of AEC professionals to interact with, understand, and trust the increasingly complex digital twins of our built environment.

References

Arundhati, G., Allan ,D. Chasey, Ph.D, PE and Scott, R. (2013) 'Industry and Academia: A partnership to VDC Curriculum'.

Atwa, S. M. H., Ibrahim, M. G., Saleh, A. M. and Murata, R. (2019) 'Development of sustainable landscape design guidelines for a green business park using virtual reality', Sustainable Cities and Society, vol. 48, p. 101543.

Blazauskas, T., Maskeliunas, R., Bartkute, R., Kersiene, V., Jurkeviciute, I. and Dubosas, M. (2017) 'Virtual Reality in Education: New Ways to Learn', in Damaševičius, R. and Mikašytė, V. (eds) Information and Software Technologies, Cham, Springer International Publishing, pp. 457–465.

Clevenger, C., Glick, S. and Del Puerto, C. L. (2012) 'Interoperable Learning Leveraging Building Information Modeling (BIM) in Construction Education', International Journal of Construction Education and Research, vol. 8, no. 2, pp. 101–118.

Davila-Delgado, J. M. et al. (2024) 'Paper Title Corresponding to ID 282', Proceedings of the 2024 European Conference on Computing in Construction (EC3).

Elgewely, M. H., Nadim, W., ElKassed, A., Yehiah, M., Talaat, M. A. and Abdennadher, S. (2021) 'Immersive construction detailing education: building information modeling (BIM)–based virtual reality (VR)', Open House International, vol. 46, no. 3, pp. 359–375.

Gledson, B. J. and Dawson, S. (2017) 'Use of Simulation Through BIM-Enabled Virtual Projects to Enhance Learning and Soft Employability Skills in Architectural Technology Education', in Dastbaz, M., Gorse, C. and Moncaster, A. (eds) Building Information Modelling, Building Performance, Design and Smart Construction, Cham, Springer International Publishing, pp. 79–92.

Kamari, A., Paari, A. and Torvund, H. Ø. (2021) 'BIM-Enabled Virtual Reality (VR) for Sustainability Life Cycle and Cost Assessment', Sustainability, vol. 13, no. 1, p. 249.

Kassem, M. and Kifokeris, D. (2025) 'Human-Data Interaction (HDI) in the Built Environment', EC3 White Paper 1.

Liu, D., Bhagat, K., Yuan, G., Huang, R. and Chang, T. (2017) 'The Potentials and Trends of Virtual Reality in Education', in, pp. 105–130.

Radianti, J., Majchrzak, T. A., Fromm, J. and Wohlgenannt, I. (2020) 'A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda', Computers & Education, vol. 147, p. 103778.

Sacks, R., Eastman, C., Lee, G. and Teicholz, P. (2018) BIM Handbook, Wiley.

Sacks, R. and Pikas, E. (2013) 'Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis', Journal of Construction Engineering and Management, vol. 139, no. 11.

Samarasinghe, D. A. S., Latif, S. A. and Baghaei, N. (2019) 'Virtual Reality Models for Promoting Learners Engagement in Construction Studies', 2019 IEEE Global Engineering Education Conference (EDUCON). Dubai, United Arab Emirates, 08.04.2019 - 11.04.2019, IEEE, pp. 1331–1335.

Sanchez, B., Ballinas-Gonzalez, R. and Rodriguez-Paz, M. X. (2021) 'Development of a BIM-VR application for e-learning engineering education', 2021 IEEE Global Engineering Education Conference (EDUCON). Vienna, Austria, 21.04.2021 - 23.04.2021, IEEE, pp. 329–333.

Shavinina, L. V. (2013) The Routledge International Handbook of Innovation Education, Routledge.

Tseng, K. C. and Giau, D. T. N. (2022) 'A feasibility study of using virtual reality as a pre-occupancy evaluation tool for the elderly', Automation in Construction, vol. 134, p. 104037.

Whyte, J. (2003) 'Industrial Applications of Virtual Reality in Architecture and Construction', vol. 8.