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Developing a Workflow for Transforming BIM Models into Immersive Virtual Reality Experiences

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Abstract

The integration of Extended Reality (XR) and Building Information Modelling (BIM) has emerged as a promising approach for enhancing interaction with spatial data in the built environment. While the potential of BIM for advanced visualization has been recognized, there remains a need for standardized workflows that facilitate the transformation of BIM models into immersive virtual reality (VR) experiences. This research contributes to the ongoing development of BIM-VR integration by presenting a workflow that leverages Revit, Twinmotion, and Datasmith to create visually rich and interactive VR environments. The established process focuses on enhancing textures, incorporating dynamic lighting and weather simulations, and populating the virtual space with realistic elements. The workflow also addresses the integration of interactable objects to elevate user engagement and the use of cutting-edge VR headsets for an immersive experience. By providing a structured approach to bridging complex BIM data with VR, this research aims to support architects, engineers, construction professionals, and clients in design collaboration, project review, and decision-making across the building lifecycle. The workflow's potential for facilities management and training applications is also explored. Through a case study, the research demonstrates the workflow's effectiveness in facilitating a deeper understanding of architectural spaces before construction, highlighting its potential for improving efficiency and reducing rework. The paper also discusses the challenges and opportunities associated with integrating BIM with GIS and sensor data to create comprehensive digital twins. This research contributes to the growing body of knowledge on BIM-VR integration and underscores the importance of continued development in this field to enhance the design, communication, and experience of the built environment.

1. Introduction

Building Information Modelling (BIM) has become the standard digital tool for project management in the architecture, engineering, and construction (AEC) industry (Avendaño et al 2023). BIM offers a comprehensive, data-rich representation of buildings, encompassing geometric and semantic information across the lifecycle of a project (Han and Leite, 2022). However, the utilization of BIM data has often been confined to traditional 2D plans and 3D models, leaving its vast potential for advanced visualization not fully exploited. The emergence of the metaverse and extended reality (XR) technologies, particularly virtual reality (VR), presents a significant opportunity to elevate the architectural visualization realm. VR enables users to experience digital environments through immersive, interactive simulations, offering a sense of presence and scale unattainable through conventional representational media (Schiavi et al., 2022).

The integration of BIM and VR has been an ongoing area of research and development in the AEC industry. Numerous studies have explored the potential benefits and applications of this integration, including enhanced design communication, collaborative decision-making, and immersive design review (Du et al., 2018; Goulding et al., 2014). However, there remains a need for standardized workflows that facilitate the seamless transformation of BIM models into engaging and interactive VR experiences.

This paper reports on research that contributes to the growing body of work on BIM-VR integration by proposing a workflow aimed at harnessing the full spectrum of BIM's visualization capabilities. The proposed workflow builds upon existing research and practices in the field, focusing on establishing a standardized approach for transitioning BIM data into dynamic, interactive virtual environments. By integrating VR, this study seeks to enhance the AEC industry's design and presentation methodologies and to foster a more intuitive connection between project stakeholders and the envisioned architectural spaces.

The paper begins by examining the need for BIM-VR integration and its potential to address the limitations of traditional architectural visualization methods. It then reviews relevant literature, highlighting key advancements and frameworks that inform the proposed workflow. The methodology section details the step-by-step process of integrating BIM and VR, from model preparation to VR experience setup. Results demonstrate the successful implementation of the workflow, showcasing its ability to transform complex BIM data into compelling, photorealistic VR environments. The paper concludes by discussing the implications of this integration for architectural design and collaboration, and outlining future research directions, particularly in the context of integrating BIM with GIS and sensor data for digital twin applications.

2. The need for BIM-VR integration

Traditional visualisation methods employed in the built environment context, such as 2D blueprints, renderings, and basic 3D models, often provide a limited representation of architectural designs. While useful for conveying general design intent, these methods may not fully capture the experiential qualities of a space, such as scale, depth, lighting, and materiality (Arayici et al., 2018). This detachment between conceptual representations and the final built environment can hinder effective communication and shared understanding among project stakeholders, including architects, engineers, clients, and end-users.

The limitations of traditional visualisation become particularly apparent in the design review and client engagement processes. 2D drawings and static 3D models often require significant interpretation and imagination to envision the final space, which can be challenging for non-technical stakeholders (Assila et al., 2022). This can lead to misunderstandings, unmet expectations, and costly changes later in the project lifecycle. Moreover, the lack of immersion and interactivity in these representations can limit the ability to explore and refine design alternatives collaboratively.

Integrating BIM with VR offers a ground-breaking approach to address these challenges. BIM models contain rich, detailed information about a building's geometry, materials, and systems, providing an ideal foundation for creating accurate, data-driven VR experiences (Wang et al., 2020). By translating BIM data into immersive VR environments, designers can create virtual spaces that closely mirror the intended built environment, enabling stakeholders to experience the design as if they were physically present.

VR's ability to provide a sense of scale, depth, and spatial relationships can significantly enhance understanding of architectural designs (Khan et al., 2021). Clients and end-users can explore virtual buildings at their own pace, gaining a first-hand appreciation of room sizes, layouts, and visual connections. This experiential understanding can facilitate more meaningful discussions and informed decision-making, reducing the risk of costly changes and rework later in the project.

Furthermore, VR's interactive capabilities open new possibilities for collaborative design and stakeholder engagement. Multiple users can inhabit the same virtual space simultaneously, enabling real-time exploration, annotation, and modification of designs (Du et al., 2018). This collaborative immersion can foster a shared vision among project stakeholders, facilitating alignment and buy-in from the early stages of the design process.

Beyond enhancing visualisation and communication, integrating BIM and VR has the potential to transform the architectural design process itself. By enabling rapid prototyping and iterative design in a virtual environment, designers can explore a wider range of options and assess their impact on user experience and building performance (Sampaio, 2018). This user-centric, data-driven approach can lead to more responsive, optimised designs that better meet the needs of occupants and clients.

The seamless integration of BIM and VR proposed in this research aims to unlock these transformative benefits for the AEC industry. By establishing a standardised workflow that leverages the strengths of both technologies, this study seeks to empower architects, designers, and stakeholders with a powerful tool for visualisation, collaboration, and decision-making. The proposed workflow has the potential to streamline design processes, improve client satisfaction, and ultimately lead to better-performing, more user-friendly built environments.

3. Literature Review

The integration of Virtual Reality (VR) in the AEC industry has been a topic of growing interest in recent years, driven by advancements in computational power, display technologies, and the increasing adoption of BIM. Numerous studies have explored the potential applications and benefits of VR in architectural design, construction, and project management, laying the groundwork for the development of integrated BIM-VR workflows.

3.1 VR in Architectural Design Communication and Evaluation

One of the most prominent areas of research has been the use of VR for enhancing architectural design communication and evaluation. (Portman et al., 2015) highlighted VR's potential to provide immersive experiences of unbuilt designs, enabling stakeholders to better understand spatial relationships, scale, and aesthetics. They argued that VR can facilitate more informed decision-making and increase client satisfaction by allowing users to explore and interact with virtual environments.

Several studies have empirically investigated the impact of VR on design comprehension and evaluation. (Khan et al., 2021) conducted experiments comparing user understanding of architectural spaces through traditional 2D drawings, 3D models, and VR experiences. Their results demonstrated that VR significantly improved participants' spatial understanding and ability to identify design issues compared to other representation methods. Similarly (Assila et al., 2022) found that VR walkthroughs enhanced clients' understanding of design intent and led to more effective communication with architects.

3.2 Technical Advancements in BIM-VR Integration

The integration of BIM and VR has been facilitated by advancements in software and hardware technologies. (Wu et al., 2021) proposed a framework for automatically converting BIM models into VR environments, leveraging game engines such as Unity3D for real-time rendering and interaction. Their approach demonstrated the feasibility of creating immersive VR experiences directly from BIM data, reducing manual effort and potential inconsistencies.

The development of high-performance computing and graphics processing units (GPUs) has been crucial for enabling real-time rendering of complex BIM models in VR. (Alizadehsalehi et al., 2020) highlighted the role of advanced hardware in supporting the visualization and manipulation of large-scale BIM data in immersive environments. They also noted the importance of optimizing BIM models for VR, such as reducing polygon counts and simplifying geometries, to ensure smooth performance and user experience.

3.3 Collaborative Design in VR

VR's ability to support multi-user experiences has opened up new possibilities for collaborative design and review processes. (Du et al., 2018) developed a collaborative VR system that allowed multiple users to simultaneously access and manipulate BIM models in a shared virtual environment. Their study demonstrated the potential for VR to facilitate real-time co-design and decision-making among geographically dispersed teams.

(Goulding et al., 2014) explored the use of collaborative VR for engaging stakeholders in the design process. They argued that VR's immersive and interactive qualities can promote active participation and facilitate the capture of user requirements and feedback. The authors proposed a framework for integrating VR into participatory design workflows, emphasizing the importance of user-centred design approaches in the AEC industry.

3.4 VR for Construction Planning and Training

Beyond architectural design, VR has shown promise in construction planning, site analysis, and personnel training.

(Sampaio, 2018) investigated the use of VR for construction safety education, developing immersive simulations of jobsite hazards to improve workers' risk perception and decision-making skills. Their study highlighted VR's potential for providing realistic, interactive training experiences that can enhance safety outcomes on construction projects. (Getuli et al., 2020) proposed a BIM-VR framework for construction site logistics planning, enabling stakeholders to simulate and optimize site layouts, equipment placement, and material flows in a virtual environment. The authors demonstrated how VR can support more efficient and collaborative planning processes, reducing the risk of spatial conflicts and improving construction productivity.

3.5 Research Gaps and Opportunities

Despite the growing body of research on BIM-VR integration, there remain significant opportunities for further investigation and development. Many existing studies have focused on proof-of-concept implementations or case studies, highlighting the need for more comprehensive, scalable workflows that can be readily adopted in practice (Banerjee and Nayaka, 2022).

Moreover, while the benefits of VR for design communication and understanding have been well-documented, less attention has been given to its impact on the design process itself. Future research could explore how VR-based design workflows influence the generation and evaluation of design alternatives, as well as the incorporation of user feedback and performance analysis (Schiavi et al., 2022)

Another area ripe for investigation is the integration of VR with other emerging technologies, such as augmented reality (AR), mixed reality (MR), and the Internet of Things (IoT). The convergence of these technologies could enable new forms of interaction and data visualization, further blurring the lines between the physical and digital worlds (Alizadehsalehi et al., 2020). Furthermore, these technologies require BIM models to be geo-references to allow integration with real-world models. The automatic referencing between project coordinates and real-world coordinates still poses many challenges (Aleksandrov et al 2019, Diakite and Zlatanova, 2020).

Finally, there is a need for more research on the organizational and cultural factors that influence the adoption and implementation of BIM-VR workflows in AEC practice. Understanding the challenges and enablers of technology adoption, as well as the impact on existing workflows and skill requirements, could help guide the development of more effective implementation strategies (Goulding et al., 2014).

The proposed research aims to address these gaps by developing a comprehensive, standardized workflow for BIM-VR integration that can be applied across a range of architectural projects. By demonstrating the workflow's effectiveness in enhancing design understanding, collaboration, and decision-making, this study seeks to contribute to the growing body of knowledge on VR's transformative potential in the AEC industry.

4. Methodology

The proposed workflow establishes a standardized approach for integrating BIM and VR to create immersive architectural visualizations. This methodology is grounded in the principles of design science, which aims to create and evaluate artifacts intended to solve identified organizational problems. In this context, the artifact is the proposed workflow for transforming BIM models into immersive VR experiences. The design science methodology involves iterative processes of problem identification, objective definition, design and development, demonstration, evaluation, and communication. This structured approach ensures that the workflow not only addresses the limitations of traditional visualization methods but also meets the practical needs of industry stakeholders.

The methodology builds upon existing work in the field of BIM-VR integration, while focusing on streamlining the process and ensuring its applicability across a range of architectural projects. The workflow leverages widely used software tools, such as Revit and Twinmotion, to facilitate adoption and implementation within the AEC industry.

4.1 Manual Steps in BIM creation

The proposed workflow begins with the initial design phase, where architects create the conceptual model of the building using their preferred software, such as Rhino, Grasshopper, or SketchUp. This phase allows for creative exploration and iterative design, as architects can quickly generate and test various design options using generative design tools and AI-assisted processes. Once the conceptual design is finalized, it is then transferred to a BIM authoring tool like Revit for further development and refinement. This transition enables the integration of more detailed information, such as material specifications, structural elements, and MEP systems, into the model. While the proposed workflow aims to automate many of the subsequent steps, the initial design phase remains largely manual, allowing for human creativity, expertise, and oversight. Architects can ensure that the design meets the project requirements, client expectations, and aesthetic vision before proceeding with the VR integration process. It's important to note that the manual steps in this phase are not focused on quality control in terms of technical accuracy, but rather on the creative aspects of the design. The subsequent phases of the workflow will address the technical quality control measures necessary for a successful VR integration.

4.2 Preparation of the Revit Model

This stage focuses on optimizing the BIM model for VR experiences. The process begins with a thorough review of the Revit model, identifying elements that may hinder real-time performance in VR. To streamline this process, the Revit model's semantic information is leveraged to automatically identify and isolate certain building elements that can be safely omitted from the VR model without compromising the overall design intent.
For instance, using the Revit model's semantic data, non-visible elements such as internal wall structures, HVAC ducts, and plumbing systems can be automatically filtered out. This automation significantly reduces the manual effort required to optimize the model for VR. However, some manual intervention is still necessary to fine-tune the model and ensure optimal performance.

The manual optimization process involves carefully examining complex geometries and textures that may not be automatically detected by the semantic filtering process. These elements are then simplified or replaced with less detailed equivalents to reduce the overall complexity of the model. For example, intricate architectural features or highly detailed furniture may need to be manually replaced with simplified versions that maintain the overall aesthetic while improving VR performance.

Next, the model is restructured to facilitate efficient data transfer and management when exporting to Twinmotion. This involves organizing model elements into clearly defined categories and layers within the Revit project, ensuring that only the necessary components are included in the VR export. For example, all architectural elements, such as walls, floors, and ceilings, should be properly categorized and placed on appropriate layers. Similarly, furniture, lighting, and other objects should be organized into their respective categories and layers. This structured organization of the Revit model ensures that the exported data is clean, efficient, and optimized for the VR experience in Twinmotion. (Figure 1).

Attention is given to maintaining accurate scaling and proportions throughout the optimization and restructuring process, as inconsistencies can lead to disorientation or misinterpretation of spatial relationships in VR. By leveraging semantic information and carefully reviewing and adjusting the model elements, designers can ensure that the virtual environment accurately represents the intended scale and proportions of the physical space while minimizing manual effort.

The size of the BIM model is a critical factor in determining the feasibility and performance of the VR experience. In our case study, we worked with a BIM model of a two-story residential building. The case study was conducted on a computer equipped with an NVIDIA GeForce RTX 4090 graphics card and 32GB of RAM. This high-end hardware configuration allowed for smooth processing and visualization of the BIM model in the VR environment. The resulting VR experience maintained a stable and interactive frame rate, ensuring a seamless and immersive user experience. It is crucial to maintain a target frame rate of at least 90 frames per second (FPS) in VR applications to prevent motion sickness and ensure a comfortable user experience. Lower frame rates can lead to visual lag, stuttering, and a disconnection between the user's physical movements and the virtual environment, which can cause discomfort and disorientation. The hardware setup used in our case study, particularly the RTX 4090 graphics card, was able to consistently deliver the required 90 FPS, providing a smooth and immersive VR experience.

It is important to note that the maximum model size that can be processed depends on various factors, such as the hardware specifications of the VR system, the complexity of the model geometry, and the desired level of visual fidelity. The RTX 4090, being one of the most powerful consumer graphics cards available at the time of the study, significantly contributed to the workflow's ability to handle the model with ease while maintaining the target frame rate.

However, it is crucial to recognize that not all users may have access to such high-end hardware. In cases where lower-tier graphics cards or less RAM is available, the proposed workflow may require additional optimization steps or may be limited in terms of the maximum model size that can be processed while maintaining acceptable performance and the desired 90 FPS.

4.3 Choosing Twinmotion Over Other Tools

One of the critical decisions in the proposed workflow is the choice of Twinmotion over other powerful tools like Unreal Engine. This choice is primarily driven by the need for an easier learning curve, advantageous licensing terms, and the tool's specific design for architectural visualization.

Twinmotion is tailored for architects and designers, offering a user-friendly interface that significantly reduces the learning curve. Unlike Unreal Engine, which requires extensive knowledge of game development principles and programming, Twinmotion enables users to quickly create high-quality visualizations with minimal training. This accessibility is crucial for professionals who need to focus on design rather than technical complexities. Additionally, Twinmotion's straightforward licensing model, particularly for educational purposes and small to medium businesses, makes it an attractive choice for a wide range of users. It provides free access for students, educators, and businesses with an annual gross revenue less than $1 Million USD (Epic Games Development Team, 2019), whereas Unreal Engine's licensing model can be more complex and costly for small-scale applications.

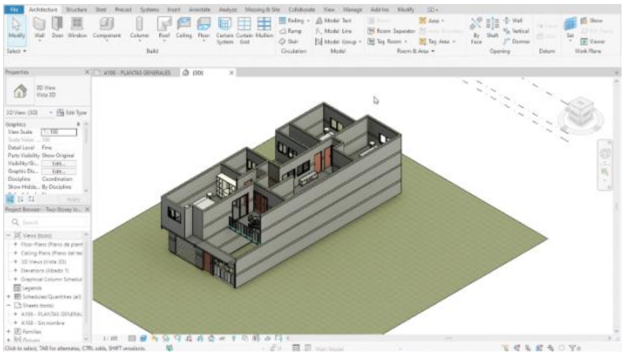

Figure 1. Model Simplified for VR

Furthermore, Twinmotion is specifically designed for architectural and design visualization, featuring direct synchronization with BIM tools like Revit, a vast library of realistic materials and objects, and real-time rendering capabilities. While Unreal Engine is a highly versatile and powerful tool, it is primarily a game engine, necessitating extensive customization for architectural use. These factors collectively make Twinmotion a more practical and efficient choice for creating immersive VR experiences from BIM models, aligning with the goal of the proposed workflow to streamline and enhance the design visualization process in the AEC industry.

Figure 2. Revit model imported to Twinmotion.

4.4 Exporting from Revit to Twinmotion

Once the Revit model is prepared, the next stage involves exporting it to Twinmotion (Figure 2), a real-time visualization tool that integrates seamlessly with BIM workflows. The export process leverages the Datasmith plugin for Revit, ensuring the accurate transfer of geometry, materials, and textures.

This direct link between Revit and Twinmotion enables a smooth and efficient workflow, allowing for iterative updates as the design evolves. Any changes made in the Revit model can be easily synchronized with the Twinmotion scene, maintaining consistency, and reducing manual rework.

4.5 Enhancing Realism in Twinmotion

The next stage focuses on elevating the visual fidelity and immersion of the VR experience within Twinmotion. This involves a combination of texture enhancements, environmental settings, and the integration of dynamic elements.

Figure 3. Adding high resolution textures

High-resolution textures, sourced from libraries such as Quixel Megascans (Figure 3), are applied to key surfaces and objects, ensuring a level of detail that closely mimics real-world materials. Attention is given to creating accurate representations of architectural finishes, such as wood grains, stone patterns, and fabric weaves.

Environmental settings, including lighting, time of day, and weather conditions, are carefully adjusted to create realistic and contextually appropriate atmospheres. The placement of natural and artificial light sources is considered to highlight key architectural features and create engaging spatial experiences. (Figure 4).

Figure 4. Updated environment

Figure 5. Adjusting the scene in VR

To further enhance the sense of immersion, dynamic elements are incorporated into the scene. These may include animated characters, moving vehicles, or interactive objects that respond to user proximity or actions. The inclusion of these elements helps to create a more lifelike and engaging VR experience.

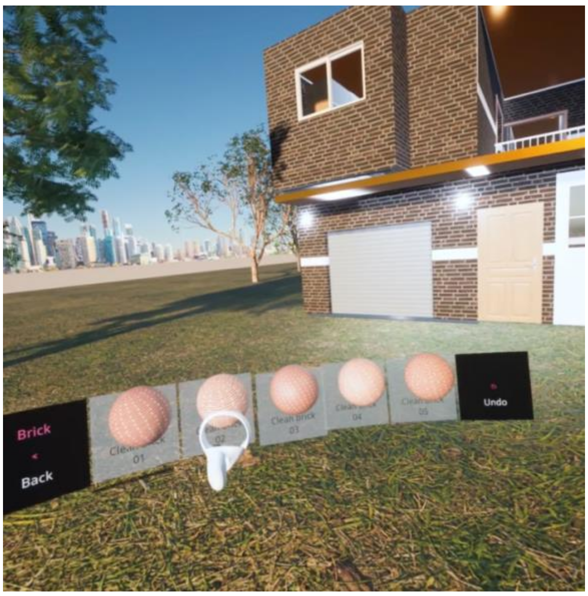

Figure 6. Updating the model in VR

4.6 Setting up the VR Headset

The final stage of the workflow involves configuring the VR hardware and software for seamless integration with Twinmotion. This process begins by setting up a compatible VR headset, such as the Meta Quest 3, and ensuring that the necessary drivers and software are installed and updated.

Once the VR headset is connected, Twinmotion automatically recognizes the device, enabling a smooth transition into the immersive experience. Users can then navigate and interact with the virtual environment using intuitive hand-held controllers, mimicking natural movements and gestures. (Figure 5).

Within the VR experience, users have access to a range of tools and settings that allow them to manipulate the scene in real-time. This may include adjusting lighting, modifying material properties, or toggling the visibility of different model layers. The ability to make changes and see the results instantly in VR facilitates rapid design iteration and decision-making. (Figure 6).

5. Results and Discussion

The proposed workflow has been successfully implemented on a case study project, demonstrating its effectiveness in transforming complex BIM data into compelling, photorealistic VR experiences. The case study involved a two-story residential building, modelled in Revit, and served to validate the workflow's applicability across a range of architectural scales and typologies. The results were externally validated through practical implementation and user feedback sessions with professionals in the AEC industry. Participants, including architects and clients, interacted with the VR environment created using the workflow and provided feedback on its usability, realism, and overall effectiveness. Their responses confirmed the workflow's ability to enhance design communication and decision-making.

The case study highlights several key benefits of the BIM-VR integration workflow, including enhanced visual fidelity and immersion, improved design communication and understanding, and streamlined design iteration and decision-making. The results demonstrate the potential for the workflow to improve efficiency and cost savings in the architectural design process by automating the conversion of BIM data into VR experiences and facilitating early identification and resolution of design issues.
However, the case study also reveals limitations and areas for future research. While the workflow demonstrates significant benefits, further testing across a broader range of building typologies and scales is necessary to validate its generalizability. Additionally, the VR experiences created in the case study were primarily visual, and future research could explore the integration of other sensory modalities to enhance the immersive quality of the experience.

The case study also highlights the importance of considering hardware and software requirements when implementing the BIM-VR integration workflow. The use of high-end hardware allowed for smooth processing and visualization of the BIM model in the VR environment, ensuring a stable frame rate and a comfortable user experience. However, it is crucial to recognize that not all users may have access to such high-end hardware, and the workflow may require additional optimization steps or face limitations when working with lower-tier systems.

Furthermore, the case study underscores the need for further research on the integration of BIM with GIS and sensor data to create comprehensive digital twins. While the proposed workflow focuses on the integration of BIM and VR, the broader challenge of integrating these technologies with GIS and sensor data remains an important area for future investigation. This integration requires addressing issues such as georeferencing BIM models, establishing common data standards, and developing efficient methods for managing and visualizing complex, multi-modal datasets.

5.1 Enhanced Visual Fidelity and Immersion

One of the most striking outcomes of the BIM-VR integration was the level of visual fidelity achieved in the resulting VR experience. The combination of optimized geometry, high-resolution textures, and carefully tuned environmental settings resulted in a virtual environment that closely matched the intended real-world appearance of the building.

Participants who experienced the VR walkthrough consistently remarked on the realism of the materials, lighting, and spatial proportions. The ability to perceive the building at a 1:1 scale, with accurate representations of colour, texture, and depth, provided a strong sense of presence and immersion.

The integration of dynamic elements, such as animated characters and interactive objects, further enhanced the lifelike quality of the experience. Participants reported feeling more engaged and connected to the virtual environment, as if they were exploring a physical space rather than a digital model.

5.2 Improved Design Communication and Understanding

The VR experience proved to be a powerful tool for communicating design intent and facilitating stakeholder understanding. Participants, including designers and consultants, were able to intuitively navigate the virtual building, gaining a first-hand appreciation of the spatial relationships, circulation patterns, and aesthetic qualities.

The ability to explore the building from multiple viewpoints and at different times of day provided a comprehensive understanding of the design that was difficult to achieve through traditional 2D drawings or static 3D models. Participants reported feeling more confident in their understanding of the project and better equipped to provide meaningful feedback.

5.3 Streamlined Design Iteration and Decision-Making

The integration of BIM and VR through the proposed workflow significantly streamlined the design iteration and decision-making process. The ability to make changes in the Revit model and see the results instantly reflected in the VR experience allowed for rapid prototyping and evaluation of design alternatives.

Designers were able to test and refine ideas in real-time, assessing the impact of different materials, colours, and spatial configurations on the user experience. The VR environment provided a more intuitive and immersive platform for exploring design options, compared to traditional methods of reviewing 2D drawings or renderings.

The collaborative nature of the VR experience also facilitated more efficient decision-making. Stakeholders were able to provide immediate feedback and reach consensus on design choices while immersed in the virtual environment. This real-time interaction helped to identify and resolve potential issues early in the design process, reducing the risk of costly changes later.

5.4 Improved Efficiency and Cost Savings

The proposed workflow demonstrated significant potential for improving efficiency and reducing costs in the architectural design process. By automating the conversion of BIM data into

VR experiences, the workflow minimized the time and effort required for manual model preparation and optimization.

The use of a unified software platform, such as Twinmotion, streamlined the data transfer and visualization process, eliminating the need for multiple specialized tools or custom programming. This integration allowed for a more seamless and efficient workflow, reducing the potential for errors or data loss. The ability to identify and resolve design issues early through VR-based design reviews also contributed to cost savings. By catching potential problems before construction, the workflow helped to minimize the need for expensive rework or change orders.

It is important to note the licensing restrictions of the software used in this workflow. Twinmotion, for example, is free for educational purposes and small to medium businesses, making it a cost-effective choice for many users. Compared to Unity and Unreal Engine, Twinmotion offers advantages in terms of ease of use and seamless integration with BIM software, which can significantly reduce the learning curve and setup time for new users.

5.5 Limitations and Future Research

While the proposed workflow demonstrated significant benefits, there are limitations and areas for future research. The case study focused on a single residential project, and further testing across a broader range of building typologies and scales would help to validate the workflow's generalizability. The VR experiences created through this workflow were primarily visual in nature, and future research could explore the integration of other sensory modalities, such as sound and haptics, to enhance the immersive quality of the experience. The inclusion of acoustic simulations, for example, could provide valuable insights into the soundscape of a building.

Another area for future investigation is the integration of the workflow with other emerging technologies, such as augmented reality (AR) and mixed reality (MR). The ability to overlay digital information onto the physical world could open new possibilities for on-site design visualization and construction monitoring. Finally, longer-term studies are needed to assess the impact of the workflow on project outcomes, such as client satisfaction, construction quality, and building performance. Tracking the use of the workflow across multiple projects and phases could provide valuable insights into its effectiveness and potential for industry-wide adoption.

It is crucial to address the challenge of integrating BIM models with GIS data and other city-scale information. One of the key aspects of this integration is the georeferencing of BIM models, which involves converting the local coordinate system used in the BIM software to real-world coordinates compatible with GIS systems.

In the case study presented in this research, the BIM model was created using a local coordinate system specific to the Revit software. However, to accurately position the model within a larger urban context and enable seamless integration with other city-scale data, it is necessary to transform the local coordinates into a real-world coordinate system, such as WGS84 or a local projected coordinate system.

The process of georeferencing BIM models can be challenging, as it requires establishing a common reference frame between the BIM and GIS data. This can be achieved with control points, which are identifiable features with known coordinates in both the BIM model and the real world. By aligning these control points, the BIM model can be accurately positioned and oriented within the GIS environment.

(Aleksandrov et al., 2019) propose a system architecture for managing BIM, 3D GIS, and sensor data, highlighting the importance of georeferencing in enabling the integration of these diverse datasets. Their research demonstrates the potential for creating a unified platform that can handle complex urban data and support various applications, such as city planning, emergency response, and asset management.

Future research should focus on developing efficient and automated methods for georeferencing BIM models, as well as establishing standardized workflows for integrating BIM, GIS, and sensor data. This integration will enable the creation of more comprehensive and accurate digital representations of the built environment, supporting a wide range of applications and decision-making processes.

6. Conclusion

This research presents a workflow for integrating BIM and VR to create immersive architectural visualizations. The proposed methodology contributes to the ongoing development of BIM-VR integration practices by establishing a standardized approach for optimizing BIM data, converting it into interactive VR experiences, and enhancing the visual fidelity and realism of those experiences.

Through a case study implementation, the research demonstrates the workflow's potential for improving design communication, facilitating stakeholder collaboration, and streamlining decision-making. The results highlight the benefits of BIM-VR integration in architectural design, including enhanced visual fidelity, improved design understanding, and more efficient design iteration.

However, the research also acknowledges the limitations of the current study and identifies areas for future investigation. These include the need for further validation across a broader range of projects, the exploration of multi-sensory VR experiences, and the integration of the workflow with other emerging technologies such as AR and MR.

Importantly, the research highlights the critical challenge of integrating BIM with GIS and sensor data to create comprehensive digital twins. While the proposed workflow focuses on BIM-VR integration, it is part of a larger ecosystem of digital technologies that are transforming the AEC industry. Addressing the challenges of data integration, georeferencing, and multi-modal data visualization is crucial for realizing the full potential of digital twins in the built environment.

In conclusion, this research contributes to the growing body of knowledge on BIM-VR integration by proposing a standardized workflow and demonstrating its application through a case study. The workflow offers a foundation for further research and development in this field, emphasizing the importance of continued investigation into the integration of BIM with VR and other digital technologies to enhance the design, communication, and experience of the built environment.

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