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Development of a BIM-based Immersive Environment: Challenges and Lessons Learned

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Creating a Virtual Reality (VR) walkthrough from a 3D building information model leads to fewer mistakes and enhanced project visualization. Visualizing a 3D model in VR reveal errors not easily seen with Building Information Modeling (BIM) software. This process helps on limiting future change orders and rework, saving time and costs for both the contractor and the owner. Immersive Virtual Reality (IVR) has capable of visualizing clash detection tools while walking around the model. IVR enables the user to walk around the model freely. This helps inspect any design errors and omissions and facilitates correcting them before drawings get issued for construction. The research objective is to assess the benefits of the Immersive Virtual Reality (IVR) walkthrough compared to a 3D model alone. This study was conducted using the Oculus Rift S headset with hand controllers, Revit, and Enscape rendering software. The paper discusses the process used for creating VR walkthroughs through this low-cost but high-performance combination. This paper also discusses where the IVR was used to identify geometry and design mistakes and helped prepare the accurate as-built model.

Key Words: Virtual Reality, Building Information Modeling, Construction Technology, Immersive Environment, 3D Model Design

Introduction and Background

Virtual Reality (VR) is one of the most exciting pieces of technology being incorporated into the construction industry today. In general, the purpose of VR applications in the built environment is to deliver lifelike simulations of existing, future, or hypothetical scenarios, spaces, and facilities, whether the final goal of the application is to support design review, facility management, or workforce training. Paes et al. (2021) define VR in the built environment context as the experience of presence (of “being there”) in a simulated architectural environment. Immersive VR (IVR)

simulations allow users to walk through and interact with the virtual environment in a first-person-view mode facilitating their understanding of a project's geometry, which contributes to minimizing construction, operation, and maintenance costs associated with flaws arising from poor design solutions or undetected design mistakes.

IVR has increased users' sense of presence in the virtual environment, leading to higher focus and attention levels while navigating the model (Paes et al., 2021). VR can also be used in the design phase by design professionals, contractors, and clients of a project. VR walkthroughs benefit design professionals, contractors, and project owners. Design professionals use this technique to find mistakes and correct them before drawings get issued for construction. Also, design professionals could use VR to show their work to clients to understand better how their finished building will look. Contractors can use VR to see how a building will look before construction begins or while it is in progress. A better understanding of the finished product will help contractors make decisions early in the construction process. Finally, VR benefits project owners because they may only have limited experience with construction documents; therefore, VR could be the only way to understand what their building will look like when completed.

VR models have been built to evaluate a prospective building's structural integrity, design, and alternative solutions (Sampaio et al., 2010). VR helps to prevent expensive rework and/or potential structural failure resulting in severe injury or death. VR is used to monitor job progress from anywhere. Researchers have found that some businesses use VR to model tasks that are in progress on job sites for review by off-site personnel (Zaker and Coloma, 2018). The same study stated that the most significant obstacles to VR in construction are the industry's resistance to change and the cost of VR devices and compatible software (Zaker and Coloma, 2018).

Hilfert and Konig (2016) highlight the need for low-cost VR solutions in construction, which uncovered simple methods that would allow any company member to develop VR models without programming experience. Decreasing the cost of VR technology opens the door to more possibilities, including the use of VR in the field of interior design. Companies have begun to use VR to design interiors and make design changes using VR technology, giving consumers a better picture of how their space will look upon completion (Kaleja and Kozlovska, 2017). However, VR is not without obstacles. Since VR is a relatively new technology, companies find it costly to keep up with the most up-to-date hardware, software, and advancements (Alizadehsalehi et al., 2020). Another exciting feature of VR technology in construction is in the educational sector. Eiris et al. (2019) explain how site visits are vital to the construction curriculum. However, many students cannot visit construction sites for various reasons. With the help of VR technology, more students can virtually walk through sites and experience what they are being taught in the classroom. Elgewely (2021) adds that through this teaching style, students showed a thirty percent increase in learning improvement compared to paper-based methods, which showed a thirteen-point eight percent increase. There is more to VR usage in the classroom, however. The use of VR increases student involvement, and if the costs of VR technology come down, it could enhance e-learning during the COVID-19 pandemic (Alizadehsalehi et al., 2021).

This study was conducted using the Oculus Rift S headset with hand controllers and Enscape rendering software. This combination was reviewed by Huang (2018) and Paes et al. (2021) and determined to be effective, especially for educational purposes, due to its low cost but high performance.

Objectives

The main objective of this study was to investigate how to create an IVR walkthrough from a Revit

model. Also, the research aimed to assess the benefits of the IVR walkthrough compared to a 3D model alone. The process discussed in this paper will take a Revit model and convert it to a desktop-based VR platform, and then a VR headset will be used to immerse the user into the same virtual environment.

Methodology

VR is used to enhance the visualization of construction projects before they are built or to view projects when a physical site visit is unsuitable. The process used in this research was to take the given PDF drawings of the existing Kennesaw State University's Campus and convert them into CAD drawings. These were then loaded into Revit, where a 3D model was developed. Developing this model included visiting the building to capture photos to ensure the model was as close to the actual building as possible. The rendering software Enscape was then procured and downloaded. Using an Oculus Rift S connected to the desktop computer running Revit via USB and Display port cables, the Oculus software, and SteamVR software, the researcher, was able to walk around the Revit model using the Oculus's hand controls and view the building in more detail than using Revit alone. This enhanced detail made design errors more apparent, and while changes cannot be made in the Enscape software, changes can be made on the host desktop computer and updated live in the virtual environment.

Development of the BIM Model

To develop an IVR walkthrough, one must first have a building 3D model. For the building selected in this study, no AutoCAD file existed for any of the three floors. Only PDF files were supplied. Figure 1 shows the floor plan CAD drawings. Therefore, the PDF files had to be imported into the AutoCAD software and redrawn in CAD format. Once the CAD drawings were completed, they were imported into Revit and redrawn again as a 3D model. Next, a site survey was conducted to gather photographs of Kennesaw State University. Following the site survey, edits were made to correct defects in the supplied PDF drawings. Once the Revit model was completed to match the actual building as close as possible, it was ready to convert into an IVR walkthrough in Enscape. In AutoCAD, the room tags were removed to make the model cleaner for import to Revit. The measurements of the ramps and level changes in the auditorium were kept for reference purposes in Revit. Figures 2, 3, and 4 depict all floor plans in Revit and the 3D model. Figure 2 is the third floor, Figure 3 is the second floor, and Figure 4 is the first floor. These floor plans were drawn in Revit using the CAD drawings as a reference. Based on the site survey, the materials picked for the model elements reflect the actual building as best as possible. The Enscape software allows users to import site context, meaning that the user can enter the geographical site address and place the model into that exact location. Enscape loads the surrounding buildings, roads, and topography for a more realistic view. Figure 5 is the 3D model of the building in the Enscape software.

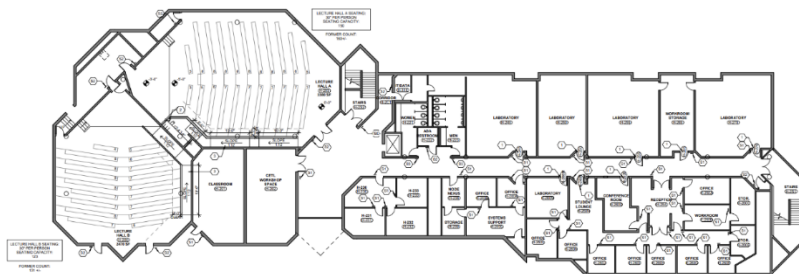


Figure 1: Floor plan (CAD drawings)

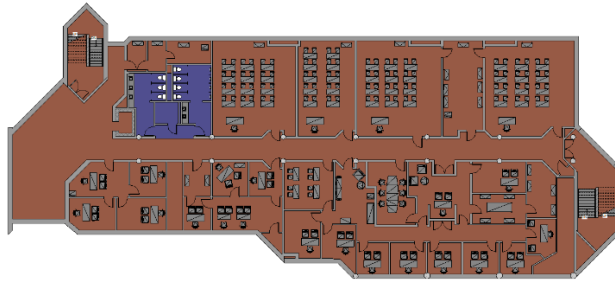


Figure 2: Third floor of the building

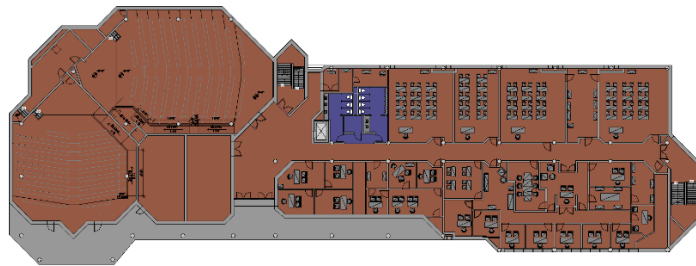


Figure 3: Second floor of the building

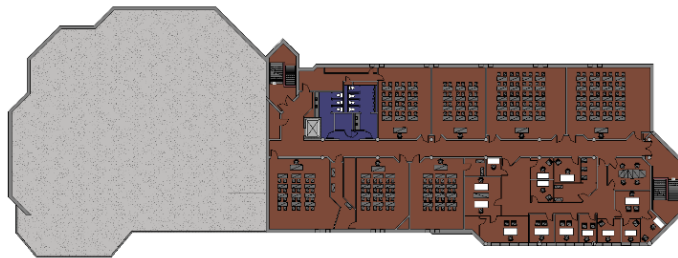


Figure 4: First floor of the building



Figure 5: 3D model of the building in the Enscape software

BIM-based IVR Simulation

This study used an Oculus Rift S headset to set up the IVR system. The Oculus Rift S requires a connection to a computer via a USB Type-A connection and a Display port connection. A Display port to a USB Type-C adapter was needed to connect to the computer used in this study. After all, the hardware was acquired, the Enscape software was downloaded from the Enscape website. Enscape software integrates into Revit automatically and projects the VR walkthrough onto the computer desktop. To get the image to appear on the Oculus Rift S headset, SteamVR must be downloaded.

SteamVR creates a link between the computer and the headset. It works similarly to adding a second monitor, whereas whatever is projected on the computer screen is launched into the headset. Once the link is created, a user puts the headset on and walks through the Revit model using the hand controls that come with the Oculus Rift S. No model edits can be made in the Enscape software; however, users can navigate and take screenshots. Enscape also allows for live updates. This means that a second user can edit the Revit model using the host computer, which will update automatically in the Enscape virtual environment.

Using IVR, the walkthrough was observed across the building in real life and the VR simulation. Figure 6 shows a comparison of the front entrance of the building in real life and the VR simulation. The curtain wall mullions had to be edited in Revit, and the ceiling had to be made at an angle to match the actual building. Figure 7 is a comparison between the existing building's main lobby and the lobby in the VR walkthrough. The ceiling and floor materials could not be found; therefore, an exact match could not be made. However, the floor plan matches the drawings provided. IVR walkthrough also observed auditoriums from inside the Enscape software. These rooms' changing levels and ramps made this the most difficult room to model. Figure 8 depicts the second-floor hall near the bathroom. Again, the brick floor texture could not be found, so it was not used. Figures 9 shows the men's bathroom inside the actual building and the VR walkthrough. Enscape could not render the bathroom countertop or the sink element from Revit. Enscape also did not render the tile flooring as well as expected. All plumbing fixtures were rendered correctly, including the urinals and water closets. Figure 10 shows a comparison of a typical classroom. This classroom is on the third floor in the construction management department. The exact desks were unavailable; however, Enscape offers its material library, and the desks depicted came from that library.



Figure 6: Front entrance, VR walkthrough vs. physical building

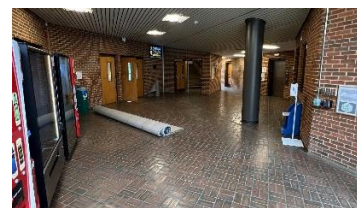


Figure 7: Main lobby, VR walkthrough vs. physical building



Figure 8: Hallway, VR walkthrough vs. physical building



Figure 9: Men's bathroom, VR walkthrough vs. physical building



Figure 10: Classroom, VR walkthrough vs. physical building

Analysis and Discussions

Some geometry mistakes were found after the IVR walkthrough was created. The IVR simulation facilitated the identification of these mistakes, which were corrected before the model was finalized. This phenomenon is similar to visual clash detection performed by professionals involved in the design process during design coordination meetings. The first mistake was a gap between the stairwell's ceiling and the floor above, as shown in Figure 11. This mistake would be difficult to see in Revit and would have been missed if the VR walkthrough was not created. This was corrected by creating a short wall that connected the ceiling to the floor above. Another mistake was that a wall in the basement was shown to be made of brick and block. This mistake is shown in Figure 12. It happened because there were two separate walls (brick and block ones) on that floor in the Revit model. This mistake was easily fixed by deleting one of the walls and editing the remaining one. Again, it is unlikely that this mistake would have been discovered using Revit alone.

The main interior stairwell is depicted in Figure 13. Enscape did not correctly render the stairs causing them to appear in bright white. Material textures can be edited in Revit, and new ones can be created

if they do not exist in the texture library. Another design mistake only discovered during the VR walkthrough was that the floor slab overlapped with the stairs in the west stairwell going from floor one to floor two, as shown in Figure 14. This mistake was fixed by editing the floor slab boundary in Revit. This mistake is visible in Revit but easily overlooked, whereas it was very apparent in VR. Additionally, in walk mode in the VR simulation, the software would not let the user move past this point which is how it was originally discovered. The construction management office hall is shown in Figure 15. The actual doors could not be found, so the standard Revit doors were used. Also, the floor plan did not seem to match; therefore, the door spacing is not exact. Object library limitations (i.e., the low variety of objects such as doors) are still bottlenecks in converting from Revit to VR. The VR simulation ends up not being that similar to the actual building. However, like textures, doors can also be edited in Revit, and new ones can be created.



Figure 11: Geometry error: the gap between the ceiling and the floor

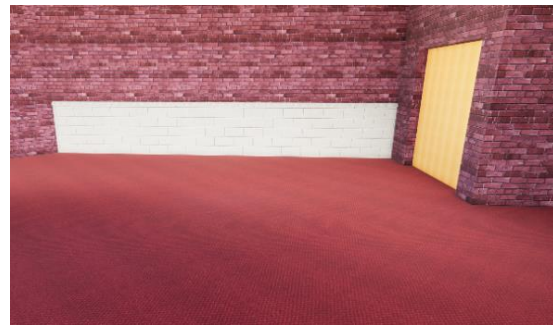


Figure 12: Geometry error: wall in the basement was shown to be made of brick and block

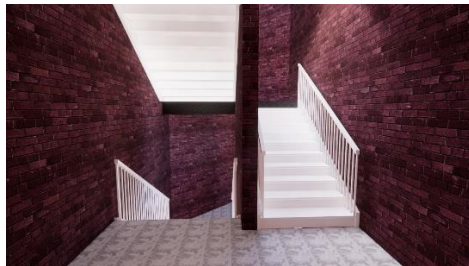


Figure 13: Design error: render the stairs causing them to appear in bright white



Figure 14: Design mistake: the floor slab overlapped with the stairs



Figure 15: Mismatch hallway doors at VR walkthrough and physical building

Conclusion

This study successfully created an IVR walkthrough of Kennesaw State University's Campus. The integration of site context was an unexpected benefit of the Enscape software; however, it was useful in seeing how the building fit on the school campus. Other benefits included finding clashes not seen in Revit alone, using Enscape's material library, and seeing the model from different viewpoints that are difficult to set in Revit. The process used in this study was found through trial and error; however, it was a straightforward process. Care should be taken to how the BIM model is developed for IVR simulation. The modeling process should mimic the as-built arrangement, so the reconstructed building is as close as possible to the physical one.

Design and contracting firms could easily use this technology in day-to-day operations. The costs saved from detecting a single future change order could return the investment of the hardware and software licenses required. Other applications of mixed-reality technologies, such as AR (Augmented Reality), involve using see-through head-mounted displays (HMDs) projecting a BIM model on top of live views of the site for construction progress inspection, ensuring that the building is completed as drawn. VR and AR combined could substantially reduce the frequency of change orders, mistakes, and rework in the construction sector. Future study is to check by enabling clash detective using VR by incorporating mixed-reality technologies to reduce change order.

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