Research and Application of BIM-Based Architectural VR Interaction Technology: Postprint

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Abstract

This study applied VR-based BIM model-data separation technology, physics-based dynamic rendering technology, and Unity secondary development technology to develop a BIM-based architectural VR interactive system through a virtual reality engine. Simultaneously, active 3D time-division display technology was investigated to form a lightweight, multi-viewer VR display solution. Application verification in the Shanghai Rail Transit Operations Command Building project demonstrates that the proposed method can accelerate the formulation of on-site decoration detailed design schemes, reduce the number of rework instances for construction mock-ups, and support its application throughout the project' s detailed design process. The approach holds promotional value in the field of architectural visualization.

Full Text

Research and Application of Building VR Interactive Technology Based on BIM

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Abstract

This research develops a BIM-based building VR interactive system by applying VR-based digital-model separation technology, physically-based dynamic rendering technology, and Unity secondary development technology through a virtual reality engine. Simultaneously, active 3D time-sharing display technology is investigated to create a lightweight, multi-viewer VR presentation solution. Application verification in the Shanghai Rail Transit Operation Command Center project demonstrates that the proposed method accelerates the formulation of on-site decoration deepening design schemes, reduces rework in

construction mock-ups, and supports applications throughout the project deepening design process. This approach holds significant promotional value in the field of architectural visualization.

Keywords: Virtual Reality; BIM; PBR Materials; Unity; Time-Sharing Display

1. Introduction

Virtual Reality (VR) is a computer technology-centered approach that integrates relevant scientific technologies to generate digital environments that closely approximate real-world environments in terms of vision, hearing, and touch. Users can interact with objects in these digital environments through necessary equipment, producing experiences and sensations of being physically present in the corresponding real scene [?]. VR technology has been widely applied in military, medical, artistic, gaming, film, entertainment, and numerous other fields. However, in China' s construction industry, research and application of VR technology still lag considerably behind developed countries. Current applications primarily focus on sample room presentations with limited technical scope, resulting in less realistic visual effects, weak interactive capabilities, and limited hardware options that require improvement.

Building Information Modeling (BIM) is a technology based on 3D digital modeling that enables the creation of intuitive, visual digital project models using computers. The advantage of BIM information models lies in overcoming the modification and synchronization bottlenecks of traditional 2D and 3D models, greatly facilitating engineering personnel through real-time, dynamic multi-dimensional models [?]. While BIM technology is rapidly being promoted in the construction industry, no genuine VR applications have been truly based on building information models.

This research separates building information models into geometric and parametric information through VR-based data-model separation technology, then imports geometric models into a VR engine for material, environment, and lighting processing using physically-based dynamic rendering technology. Subsequently, VR interactive functions are developed based on Unity, culminating in a packaged BIM-based building VR interactive system. Finally, time-sharing display technology presents the system in 3D. In summary, this paper investigates BIM-based building VR interactive technologies, focusing on data-model separation, physically-based dynamic rendering, Unity secondary development, and time-sharing display.

2.1 VR-Based Data-Model Separation Technology

As a BIM modeling software, Revit contains both geometric and parametric information. This research independently developed a Revit plugin using .NET programming and database technologies. As shown in [Figure 1: see original paper], the plugin can read parameter information from all model components based on inherent model rules, aggregate the data into custom-formatted tables, and establish mutual mapping relationships to complete data-model separation, forming a relational database uploaded to the cloud.

The plugin provides open database interfaces for the Unity VR engine, allowing download of relevant component data such as clear heights, room counts, door/window quantities, and switch counts based on project requirements. Data is called in the Unity backend to enable BIM-based building information VR presentation. During Revit modeling, each component generates a unique ID name, which is used to precisely relink components with their information during data-model merging, ensuring zero-error integration.

2.2 Physically-Based Dynamic Rendering Technology

Real-world object surfaces are covered with materials, textures, and colors that express their properties. Accurately representing these attributes in virtual scenes is crucial for achieving realism and authenticity, and proper utilization can present complex details [?] to enhance user experience.

Physically-Based Rendering (PBR) is a shading and rendering method [?]. Current PBR algorithms are based on Cook-Torrance BRDF theory and applied in shading models for both direct and indirect lighting [?]. PBR controls rendering effects through optical physical laws (primarily Fresnel reflection, microfacet theory, and energy conservation), representing the interaction between light, material properties, and environment in a physically accurate manner. Traditional rendering requires manual estimation of final effects based on experience, which may deviate from reality. Physically-based rendering technology ensures more authentic results.

This research uses Substance Designer (SBS) software with logical linking algorithms to procedurally generate textures through code, dynamically creating texture effects. Code parameters control texture properties such as scale, density, length, and contrast. For example, wood materials can have programmatically controlled rust range, corrosion degree, and size, as shown in [Figure 2: see original paper]. Traditional artistic workflows rely on manual painting, which cannot be quickly modified according to project needs. Dynamic texture technology significantly enhances texture applicability and project efficiency.

This research has established a complete physically-based dynamic rendering workflow for BIM models, as shown in [Figure 3: see original paper]. The process involves BIM model export, optimization, merging, and texture creation, producing render-ready models. Through this standardized workflow and parameter control, team members can rapidly, efficiently, and collaboratively transform BIM models into rendering models.

2.3 Immersive Simulation Interaction Technology

Multi-functional interaction technology is key to enabling users to obtain sensory perceptions (auditory, tactile, haptic, and force feedback) from virtual environments similar to real environments. This encompasses sensor technology, recognition and positioning, speech synthesis, visual tracking, perception modeling, text recognition, and devices such as data gloves and suits [?].

Unity3D is a professional cross-platform game development and VR engine created by Unity Technologies. As a specialized VR engine, Unity' s streamlined, intuitive workflow and powerful toolset significantly reduce VR program module development cycles. By integrating 3D models, textures, images, videos, and audio resources through Unity' s scene construction modules, users can easily create complex VR environments deployable on Windows, Mac OS X, Linux, and other platforms.

The immersive simulation interaction module developed in this research enables users to control virtual avatars in real-time through external hardware devices, interact with environmental components, and simulate user requirements. Taking the material replacement module as an example, the workflow is shown in [Figure 4: see original paper]. Designers provide preset materials to VR engineers, who then input various material types (partition wood finishes, stair handrail finishes, seating, lobby carpets, etc.) into the database. Through Unity' s API (Application Programming Interface), the platform links to the database, allowing designers to click UI control buttons to read material resources and replace materials for selected components, as demonstrated in [Figure 5: see original paper].

2.4 Time-Sharing Display Technology

Head-mounted displays have become mainstream VR display devices, but practical experience reveals high usage barriers. Users require specialized guidance and repeated instruction before successfully experiencing VR, while simultaneously overcoming unfamiliarity with the scene, unclear operation methods, discomfort with VR viewing, and heavy equipment. Moreover, single-user devices prevent users from clearly communicating their experiences to external observers, substantially reducing presentation efficiency.

Time-sharing display technology is a lightweight VR approach based on active 3D technology. Active shutter 3D technology splits images frame-by-frame into two sets of continuous interlaced frames corresponding to left and right eyes. An infrared signal emitter synchronously controls the left and right lens shutters of 3D glasses, ensuring each eye sees the appropriate frame at the correct moment, as shown in [Figure 6: see original paper].

This research developed a BIM VISION control plugin for time-sharing display technology based on the Unity3D engine, with the technical route illustrated in [Figure 7: see original paper]. When BIM VISION is activated, the plugin calculates and transfers model vertex coordinates, face information, and camera positions to GPU memory, then calls the graphics card for linear matrix calculations. Using the original scene camera as a base point, it renders views extended approximately 3 cm to the left and right to simulate binocular vision. After conversion, the scene is packaged into an .EXE file in the VR engine for deployment on configured hardware. Users only need lightweight glasses weighing approximately 300g to view 3D scenes. The BIM VISION plugin interface is shown in [Figure 8: see original paper].

Time-sharing display technology addresses the inefficiency of head-mounted devices and associated high per-user costs. While maintaining 3D effects and high-fidelity visuals similar to VR, the 3D movie-like presentation ensures clear communication of discussion focus among users. The lightweight glasses provide nearly zero unfamiliarity or heaviness.

3. Engineering Application Verification

In the Shanghai Rail Transit Operation Command Center project, the BIM-based building VR interactive technology was applied to the ninth-floor command center, first-floor lobby, and basement machine room for visualization, design scheme comparison, and immersive clearance height experience. On-site designers used the system to simulate main circulation routes, employing physically-based dynamic rendering to authentically represent the environmental atmosphere of three spaces, providing owners with intuitive understanding of the overall decoration ambiance.

During design review meetings, the immersive simulation interaction technology enabled designers to freely switch perspectives and conduct walkthroughs of design details, integrating multiple scenes into one system to overcome the limited viewpoints of single renderings. The interaction system replaced materials for lobby handrail finishes, seating, lobby carpets, and other components while displaying material information through data-model linkage, as shown in [Figure 9: see original paper]. This significantly reduced the number of review meetings, avoided extensive design modifications in construction mock-ups, and improved overall project progress.

In the project' s VR platform computer room environment, the system not only simulated the post-completion environment but also provided intuitive clearance height experience through VR head-mounted hardware. Real-time adjustments to mechanical and electrical pipelines above the ceiling minimized their impact on clearance height, as demonstrated in [Figure 10: see original paper].

In the command hall environment, time-sharing display technology presented the post-completion scene using active 3D technology. As shown in [Figure 11: see original paper], compared to head-mounted displays, time-sharing technology offers greater freedom, lighter weight, and multi-viewer capability, enabling VR presentations that enhance model immersion and engagement during reporting.

4. Conclusion

This research addresses construction industry characteristics by investigating BIM-based VR interactive technology and developing a project-specific BIM-based VR interactive system with functional modules including autonomous roaming, material replacement, and component substitution. Application experience yields the following conclusions:

1. For construction industry characteristics, the research establishes a workflow for BIM models to interface with VR engines through data-model separation, achieving VR-based information visualization by reading external databases.

2. Applying optical physical laws to control rendering effects creates more realistic architectural scenes and enhances designers' understanding of material physical parameters. Dynamic texture technology significantly improves texture applicability and project efficiency.

3. Immersive simulation interaction technology, developed through Unity secondary development according to client requirements, enhances system practicality and operability. It reduces decoration deepening design modifications, improves design efficiency, and increases scene interactivity, immersion, and authenticity.

4. The BIM VISION control plugin for time-sharing display technology enables user experience with lightweight glasses alone, making VR presentations multi-user, lightweight, and flexible.

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Note: Figure translations are in progress. See original paper for figures.