# Enhancing Home Design with Virtual Reality: A Study on Interactive 3D Modeling and Simulation

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**Abstract**

**This paper explores the application of Virtual Reality (VR) technology in home design. By leveraging VR, users can experience a more immersive and interactive exploration of their future homes. The study demonstrates how importing household designs and real 3D models, combined with Virtual Reality Modeling Language (VRML) and interactive links, allows for the rapid creation of furniture designs within a web-based 3D VR system. This system supports a variety of interactive methods, enabling users to adjust and compare designs to better understand the final appearance of their homes, thus enhancing customer satisfaction. Additionally, the system facilitates virtual simulation for design practice. Engineering evaluations show that the system is efficient, accelerates the design process, and reduces costs, proving its significant value in practical applications. This article offers a novel perspective on utilizing VR technology for home design.**

**Keywords*:* Virtual Reality (VR), Home Design, 3D Modeling, Virtual Reality Modeling Language (VRML), Interactive Design.**

## I. INTRODUCTION:

With the growth of China's real estate market and rising living standards, there is an increasing demand for sophisticated home design. Integrating Virtual Reality (VR) technology into interior design allows homeowners to experience a more realistic and immersive view of their future spaces. By developing virtual simulation systems, users can interactively explore and assess design effects. VR technology enhances both design quality and effectiveness, offering a new dimension to the design process.

In 2018, the Ministry of Education in China introduced the "new engineering" teaching reform strategy, which has popularized virtual simulation teaching combined with VR technology in higher education [1]. As computer technology advances, VR has emerged as a crucial tool for designers, offering innovative methods for showcasing final design outcomes [2].

The rapid evolution of network technology has also broadened the application of VR, with Web3D technology, including Virtual Reality Modeling Language (VRML), playing a key role [3]. VRML is an object-oriented 3D modeling language designed for describing interactive 3D objects and has become a standard in Web3D technology [4]. Its PROTO statement feature allows users to create custom model objects with class-like properties, encapsulating data and methods. VRML supports routing for data input and output, facilitating the creation of visual virtual scenes through script programming, which enhances user interaction and work efficiency [5].

VRML enables the definition of various interactive prototype objects, including functionalities such as clicking, translation, rotation, and selection. Its extensive interactive methods, scalability, and ease of learning make it ideal for developing VR-based virtual display systems for home design [6]. This paper proposes a home design framework based on Web3D technology, utilizing VRML and engineering practices to offer a comprehensive approach to virtual home design [7].

## II. The Proposed Virtual Reality Technology

Virtual Reality (VR) technology creates immersive, computer-generated environments that simulate real or imagined worlds. Users interact with these environments through specialized hardware like VR headsets, gloves, or controllers. The headset, equipped with motion sensors and displays, shows a 360-degree view, responding to the user's movements to make them feel as if they are physically present in the virtual space. VR is used in various fields, including gaming, education, training, healthcare, and design. It allows users to experience simulations that can replicate real-world scenarios or entirely fictional environments.

### Concept of VR technology

Virtual Reality (VR) is a highly integrated technology that combines artificial intelligence, human-computer interaction, sensing, computer graphics, and related fields to create immersive, 3D experiences. By generating realistic audio-visual simulations, VR enables users to interact with virtual environments through specialized devices, such as VR headsets. As users move, the system processes complex computations in real-time to display precise 3D images, creating a strong sense of presence.

VR technology incorporates cutting-edge advancements in computer graphics, simulation, artificial intelligence, sensing, display, and network processing, forming a sophisticated simulation system. Users can virtually immerse themselves in and control these environments for various purposes.

For a VR system to function effectively, seamless integration of various technologies is required. Key components include information synchronization, system measurement, numerical conversion, and data synthesis technologies. VR is the most effective tool for building photorealistic environments that offer real-time interaction, providing users with realistic feedback and immersive experiences.

### Advantages of VR technology

Traditional design methods often face limitations in effectively conveying ideas and can sometimes lead to miscommunication or misunderstanding between designers and customers. VR technology, however, offers a transformative solution by allowing customers to interact directly with a virtual representation of the design. Through immersive, real-time experiences, users can provide immediate feedback and make more informed decisions about modifications to the design. With VR, customers can visualize and assess various design elements, such as furniture size, placement, color schemes, lighting, and décor, in a fully interactive 3D environment. This hands-on approach eliminates guesswork and enhances collaboration, enabling customers to fine-tune their preferences and create a design that best suits their needs and style. Additionally, VR allows for a more efficient decision-making process, reducing the likelihood of costly post-installation changes. This technology revolutionizes the design process, leading to higher customer satisfaction and more tailored solutions.

VR technology offers a dynamic, real-time interactive platform that allows customers to fully immerse themselves in the design environment. It enables users to experience the space firsthand and make adjustments to key elements such as height, layout, and different design options. This level of interaction ensures that customers can fine-tune every aspect of the design to meet their specific needs. In addition to immersive visualization, VR provides precise data, including dimension and area measurements, which significantly speeds up the design process. These real-time measurements help designers and customers make informed decisions quickly, reducing delays and improving accuracy. By streamlining the design and decision-making process, VR technology saves valuable time, facilitating faster project approval and expediting the start of construction. The ability to preemptively address potential issues and experiment with multiple design iterations in a virtual space also reduces the likelihood of costly modifications later on, ultimately leading to more efficient project execution.

VR technology is not just a display medium, but also a powerful design tool that brings a designer's vision to life in a visual and interactive form. Traditionally, designers have had to rely on detailed drawings to convey their ideas, considering every aspect of the interior structure. These drawings, filled with technical data and complex content, are often difficult for non-experts to fully understand. VR technology transforms this process by converting intricate design concepts into visible, immersive virtual environments. This allows designers to present their ideas in the most intuitive and accessible way, making it easier for clients to grasp and engage with the proposed design. As a result, the entire design process becomes more efficient, as clients can visualize the space and provide real-time feedback, while designers can make adjustments instantly. VR

also enhances the overall quality of the design by allowing for more creative experimentation and ensuring that the final product is both practical and visually compelling. This shift from traditional design methods to VR-driven visualization significantly improves both the efficiency and effectiveness of the design and construction process.

In traditional design presentations, scale models and renderings have been commonly used. However, these methods come with limitations. Scale models only offer a reduced, miniature view of the design, while renderings are restricted by fixed camera angles, showing the space from a single perspective. Neither method provides a true sense of scale or allows clients to fully experience the spatial arrangement.VR technology overcomes these limitations by providing an immersive, full-scale experience. It enables clients to explore the design in real time, walking through spaces and viewing them from a human perspective. Customers can experience the actual scale and proportions of furniture, the texture of materials like curtains, and the overall layout in a way that feels real. This interactive, lifelike experience helps clients make more informed decisions about design elements, resulting in better alignment with their vision and greater satisfaction with the final outcome.

## III. WEB3D-BASED VIRTUAL REALITY SYSTEM ARCHITECTURE FOR IMMERSIVE HOME DESIGN

The Virtual Reality (VR) system architecture for home design based on Web3D integrates web-based 3D technologies to deliver immersive, interactive design experiences accessible through standard web browsers. A VR system architecture for home design using Web3D creates an accessible, interactive, and immersive design platform that transforms the client experience, allowing for real-time customization and collaboration through the web.

### Current Trends and Challenges in Home Design

When decorating a new home, most homeowners have limited understanding of the space and often lack a clear vision for layout and functionality. Communication between homeowners and designers typically follows a traditional process: designers present floor plans, along with reference materials like similar renderings or real-life photos. In some cases, 3D animations are used to showcase certain design aspects. However, these methods fail to provide homeowners with an accurate sense of what the final result will look and feel like. This often leads to dissatisfaction when the completed project doesn't match the owner's expectations.In real estate, developers often rely on model homes to give potential buyers an idea of the final look. However, building these model homes requires significant resources, and the number of models that can be created is limited. This creates a gap between the homeowner’s expectations and the actual final product.

Using virtual reality (VR) technology to display the final design and decoration during the planning process has become a critical solution. VR allows homeowners to experience the design in an immersive, realistic environment, offering a true sense of scale, layout, and materials. This not only enhances communication between homeowners and designers but also ensures that the final result aligns with the owner's vision, reducing misunderstandings and improving overall satisfaction.

### Virtual Reality Home Design System Powered by VRML

Functional requirements and technical approach for a 3D home design virtual Display system, free Roaming and interaction users must be able to navigate freely through the virtual environment. This allows homeowners to explore various rooms and functional areas, experience different design styles, and assess spatial scales before actual decoration. Customizable furniture options users should have the capability to query information about furniture and modify design elements as the explore. This includes selecting furniture colors, changing styles, and adjusting the position and orientation of furniture to meet individual preferences. Spatial understanding and design feedback. Users need to observe and interact with the entire space to understand functional partitions, spatial scales, and traffic flow post decoration. This will enable them to perceive the overall effect in advance, provide feedback, and facilitate effective communication with designers. Technical approach using VRML the based on the above requirements, this paper proposes a technical route leveraging VRML to develop a 3D home design virtual display system. The approach aims to

fulfill the functional needs of both designers and homeowners, enhancing the design experience and improving communication.

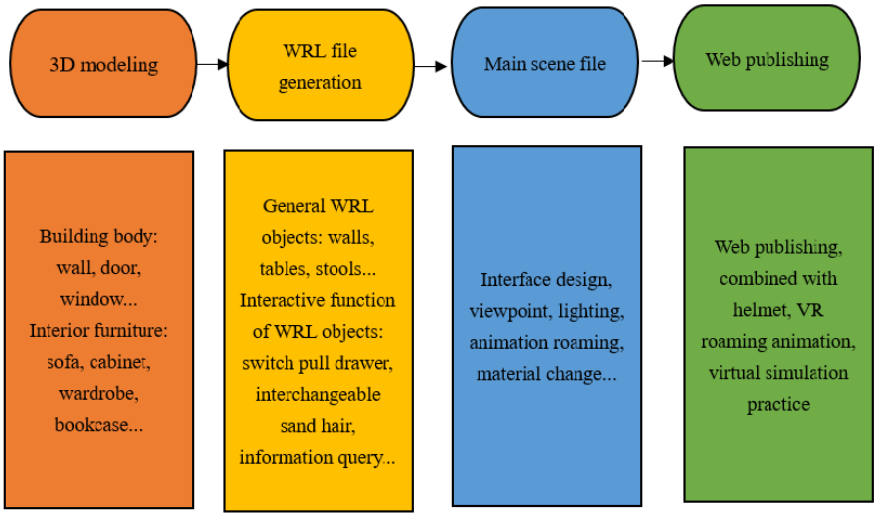


**Figure 1 Flow Chart of Virtual Reality System for Home Design**

Virtual reality home design workflow: modeling in 3DS Max begin by importing the original CAD layout into 3DS Max for 3D modeling. Key elements like walls, doors, windows, and furniture are created. Once the modeling is complete, apply real-world material textures and perform baking to achieve accurate lighting and shading effects. Generating interactive WRL object files using specialized plugins, convert the 3D models into WRL (Virtual Reality Modeling Language) object files. For interactive elements like doors and windows, create separate models to accommodate functionality. After generating these WRL files, embed interactive scripts that allow user interactions, such as opening doors or pulling drawers. These files are then compiled into the main scene. Building the main virtual scene use the inline node command to assemble individual WRL object files into a cohesive 3D virtual scene. Add features such as viewpoints, lighting, a roaming system, and interactive links to enable users to explore the virtual environment seamlessly. Publishing the VR Design, finally customize the user interface using HTML and release the VR experience through Web3D technology. Users can access the VR-enabled home design directly on the web, allowing for immersive virtual simulations and interactive design exploration

## IV. Scene Model Construction

### Modeling the content

A 3D home design system based on VR technology requires highly detailed models for every piece of furniture, all of which must be accurately modeled to the real-world dimensions from architectural drawings. This includes not only the external appearance but also the internal structure of each item. In virtual home design, interactive features that allow users to explore both the exterior and interior of furniture are critical for a fully immersive experience.VR modeling has distinct requirements compared to traditional home design renderings. While traditional methods may not necessitate modeling every object in detail, VR systems require comprehensive scene modeling. This includes walls, flooring, doors, windows, and all internal and external elements of the furniture. Every object, from large structural components to small interior details, must be faithfully recreated.For the interactive design aspect, specific attention is given to furniture like doors, windows, wardrobes, cabinets, and shoe racks. These elements are modeled separately as MAX files and converted into individual WRL object files. This modular approach allows for easier interactive design and management within the virtual scene, ensuring that users can interact with these elements seamlessly in the VR environment.

### Model optimization

To ensure optimal display performance in VR systems, which require real-time rendering at a minimum of 12 frames per second, it is crucial to optimize 3D models effectively. Here are the key strategies for achieving this: (1) Polygon Optimization: Models should be neither overly detailed nor excessively

simplistic. Using polygon modeling, avoid redundant elements and streamline the model to balance detail and performance. (2) Selective Detail: Reduce unnecessary fine details based on user needs. This minimizes the complexity of the model while maintaining visual fidelity where it matters most. (3) Bump Mapping: Implement bump maps to simulate detailed textures on surfaces without increasing the number of polygons. This technique enhances the appearance of furniture and other elements while keeping the model's surface count low. (4) Level of Detail (LOD): Utilize VRML's LOD (Level of Detail) nodes to create multi-level detailed models. This approach allows dynamic adjustment of model detail based on user proximity and interaction, improving rendering efficiency and system performance.

By applying these optimization techniques, the VR system can deliver high-quality, real-time rendering while maintaining smooth performance and a visually appealing experience.

**Main scene generation and interactive design**

To integrate independent furniture, doors, and windows into a 3D home design virtual system, which includes model, viewpoint, and lighting design, the key lies in properly positioning these elements within the main scene. After completing the 3D model, separate WRL object files are created for each piece of furniture and door/window for subsequent interactive design, rather than directly integrating them into the overall scene. To align these objects with the design layout, each furniture item is treated as a whole and positioned based on a reference point. This reference point is defined using the VRML world coordinate system. By utilizing the Transform node in VRML, each piece of furniture is positioned at its correct location in the scene. The Inline node is then used to integrate the corresponding WRL file for each object. Additionally, interactive features, such as doors opening or drawers sliding, are encapsulated within these WRL files through the use of event-based interactions.As shown in figure 2, the reference point of the desk model in the case (3 900, -5 700,0) is converted.The reference point in VRML space is (3 900,0,5 700),Thus, the Transform {translation 3 900 0 5 700 children [Inline {url "bookcabinet. WRL "}]} can be added to the WRL object file of the desk.

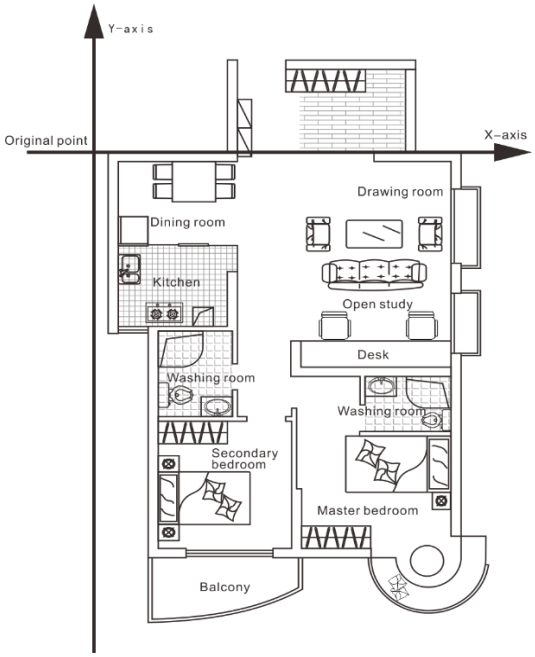


**Figure 2Layout of interior furniture nodes**

Finally, a general main scene file is established. In addition to using Transform/Inline node to integrate all model files in the same document, navigation nodes, viewpoints, lighting nodes, navigation maps and other related nodes must be defined.

View design in the main scene, predefined viewing positions and orientations allow users to explore the virtual environment as if they were looking through a camera. VRML provides Viewpoint nodes to set these camera perspectives. The position field specifies the viewpoint's location within the scene, while the

orientation field determines the direction the camera is facing.Multiple viewpoints can be defined in VRML, but only one can be active at a time. Users can switch between these viewpoints to navigate different parts of the virtual space. In this case, nine viewpoints are set up, covering areas like the entryway, living room, dining room, bedroom, and more. As shown in figure 3, the viewpoint code is as follows. DEF view0 viewpoint {position 3 200 1 600-2 200 # Viewpoint; Orientation 0 103.14159 # orientation;} … (other 8 viewpoints) …

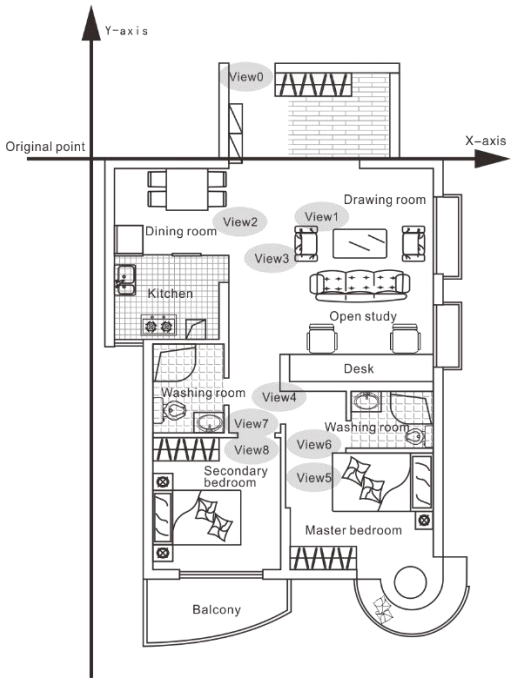


**Figure 3Layout of plane viewpoints**

Interactive design of furniture When a user roams through a VR interior space, they should be able to experience the true dimensions of the space while also interacting with the furniture in real-time. This includes getting relevant information about the furniture, adjusting its orientation or position, and changing its style to achieve the best interior design and comfort. Such interactivity can be achieved through features like information queries, furniture position and orientation adjustments, and style changes.In a VRML-based system, the interactive furniture information query can be implemented using the Transform2D node to display details about a piece of furniture. These details can be activated through a touch sensor, allowing users to query information about the furniture in real time. For example, in a children's room, querying information about an armchair could display details such as the name, front width, side width, seat width, total height, chair frame material, surface material, floor mat material, reference price, and other relevant parameters.

**Table 1: Information query diagram of furniture**

| **Furniture information** | |
|---|---|
| Name | Armchairs |
| Front width | 70 cm |
| Side width | 80 cm |
| Seat width | 50 cm |
| Total Height | 100 cm |
| Frame Material | wood |
| Surface Material | Leather |
| Floor Mat Material | Wool |
| Reference Price | $250 |

In VRML, adjusting the position and orientation of furniture is accomplished through geometric translation and rotation nodes. These allow users to move and rotate objects within the virtual environment. To replace furniture, the Switch node is used to toggle between different models or styles of furniture.User interaction is captured through routing, which records data such as translation, rotation, and replacement actions. This data is stored in a database as part of the furniture design adjustment scheme, enabling the system to track user preferences and configurations.

Interactive furniture displays in VRML rely on the platform's animation and interactivity capabilities, which are some of its most compelling features. VRML animations are driven by time sensors and various interpolators that control the scene's movements. The core principle is that time sensors act as clock generators, defining start and end times, intervals, and other control parameters. Through interpolation nodes, key points and values are set, and the system uses linear interpolation to generate smooth, user-defined animations.For instance, in a virtual shoe cabinet, the interaction can include animations for pulling out drawers or opening cabinet doors. The system detects the user's actions and adjusts the degree to which the drawer is pulled or the door is opened, creating a highly interactive experience. This functionality helps users visualize furniture use in a given space, providing valuable insights for their design decisions.In a 3D modeling tool like 3ds Max, each component of the furniture (e.g., drawer doors, internal compartments, and handles) is grouped together. To simulate the push-pull effect of a drawer, a PlaneSensor is used in VRML. This sensor allows the user to interactively push and pull the drawer along the X-axis, with a maximum movement range of 200 units, creating a realistic and intuitive experience.This approach offers users a dynamic and engaging way to explore furniture functionality, giving them a better understanding of how the furniture operates within the virtual space, and serving as a valuable reference for furniture selection

## V. Disadvantages in the Application of Technology in Home Design

### Learning Curve Challenges

The software for 3D home design remains complex and is often fragmented across various tools, requiring designers to invest many years of dedicated learning to master and use them effectively. This results in high learning costs and a steep learning curve. Additionally, for consumers attempting self-assembly or participation in the design process, the complexity of rendering software, materials, and lighting systems can be particularly challenging. Without expertise in physical optics and computer graphics, achieving the desired design outcomes is difficult.

### Duplication of Effort

Current 3D modeling and 2D drawing tools operate separately, leading to inefficient workflows and duplication of effort. Most 3D modeling software imports 2D floor plans to generate walls through extrusion. However, any modifications made to 3D models or 2D drawings are not automatically synchronized. This lack of integration results in repetitive labor and the need for manual updates, causing inefficiencies and increasing the potential for errors.

### High Costs

3D modeling tools are not specifically tailored for interior design, which makes producing comprehensive design solutions time-consuming and costly. The process involves significant effort and extended timelines. Designers often face the risk of client-driven changes, which can necessitate starting over and incurring additional costs. To manage expenses, many interior design projects rely on 2D construction drawings and perspective-based effect renderings, rather than fully integrated 3D solutions.

## VI. Conclusion

The development of a 3D home design virtual reality system utilizing Virtual Reality Modeling Language (VRML) offers several advantages, including concise coding, low development costs, and a short development cycle. By integrating prototype objects, navigation maps, and other modular functions, the system delivers a highly immersive experience and can be easily deployed on the Internet, facilitating business promotion.The system is also suitable for use in virtual simulation teaching projects, particularly in interior space design education. It represents a significant advancement in indoor decoration engineering

practices by incorporating VR technology. Users can interactively modify furniture placement, replace items with different sizes and styles, and visualize the effects of various décor choices in real-time, enhancing their understanding of the final design.The system allows users to compare different decorating outcomes and select their preferred design plan, improving overall satisfaction. Engineering practice has demonstrated that VRML's simplicity and high code efficiency accelerate home decoration design processes, saving both time and costs, and proving its substantial value in practical applications.

In home design, the application of Virtual Reality (VR) technology holds significant practical value and importance. Key challenges in home designsuch as innovation, customization, and adaptabilityare effectively addressed by VR technology. It accelerates the design process and brings a fresh dynamism to the industry.VR technology enhances understanding and communication between designers and clients, bridging gaps that often exist in traditional design processes. Additionally, it elevates the technical sophistication of the home design sector, offering new impetus for industry-wide advancement.

## VII. ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” afterthe “g”. Avoid the stilted expression, “Oneofus(R.B.G.)thanks...”. Instead, try“R.B.G.thanks”.Put applicable sponsor acknowledgments here; DO NOT place the monthefirst page of your paperorasa foot note

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