Immersive Visualization of Home Renovations for Accessibility Using Virtual Reality

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Abstract: Designing accessible spaces is a key challenge in contemporary architecture, especially when adapting existing housing. People with reduced mobility face physical barriers in their homes that affect their quality of life, and a personalized renovation helps address this. However, 2D floor plans are hard to interpret for non-experts, making it difficult to envision changes. Immersive technologies like Virtual Reality (VR) enable first-person exploration of architectural spaces, improving spatial understanding and decision-making. This work presents a VR tool that reconstructs and visualizes an apartment from CAD drawings, allowing users to move through the space, collide with different objects and obstacles, and switch between the current state and a proposed post-renovation layout.

1 Introduction

Accessibility has become a critical dimension of architectural design, particularly in the renovation of existing housing stock. Conventional workflows rely heavily on 2D technical drawings, which remain difficult to interpret for most stakeholders, including those directly affected by accessibility limitations. This gap hinders effective communication between architects, professionals, and end users, and often reduces the impact of otherwise well-conceived renovation proposals. Virtual Reality (VR) technologies offer a promising means to bridge this gap: by enabling immersive, first-person navigation of living spaces, VR can support both technical evaluation and participatory decision-making (Chowdhury and Schnabel, 2019; Tarpio and Huuhka, 2022).

In this work, we introduce a VR tool that reconstructs 3D models of apartments from 2D floor plans, with the ability to toggle between pre- and post-renovation layouts. Beyond visualization, the system allows users to interact with the environment, detect collisions, and assess maneuverability, thus providing a concrete framework for evaluating accessibility improvements. The design emphasizes modularity: the two main components—Blender, for generating 3D geometry from CAD drawings, and Unity, for interactive VR visualization—are deliberately decoupled, making it straightforward to replace or extend either module without disrupting the pipeline. This modular approach facilitates the integration of immersive methods into architectural practice while remaining adaptable to evolving tools and requirements.

The rest of the paper is organized as follows. Section 2 reviews related work on accessibility assessment and VR in architectural design. Section 3 presents our semi-automatic pipeline for generating an interactive VR experience from 2D CAD drawings. Section 4 describes the VR user interaction. Section 5 evaluates the prototype, and Section 6 concludes and outlines future work.

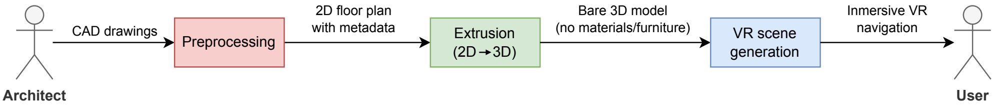


Figure 1: Workflow from CAD drawings to immersive VR exploration.

2 State of the Art

Research has increasingly explored Extended Reality (XR), particularly VR, as a medium to enhance spatial comprehension and user engagement in architectural contexts. For example, Portman et al. (2015) review the use of virtual environments in urban planning and architecture, highlighting their potential for immersive exploration of projects before construction.

From an accessibility-focused perspective, the pioneering work by Kim et al. (2008) proposed a VR-based system that allows experts to analyze architectural features and identify potential barriers for wheelchair users through virtualized 3D models. This approach enables accessibility evaluations to be conducted remotely, overcoming geographical or mobility limitations, anticipating many current applications of immersive technologies.

Considering more recent works, Götzelmann and Kreimeier (2020) develop a VR urban simulation to evaluate the inclusion of wheelchair users in smart city environments. This line is extended in Brogle et al. (2024), analyzing how immersive simulation can raise awareness among non-disabled users about existing architectural barriers.

In Tarpio and Huuhka (2022), VR is used to assess residents' preferences regarding adaptable housing, providing evidence that the technology facilitates participatory design and opinion gathering. A particularly relevant study is Hwang and Shim (2021), which examines various ways VR has supported home renovation processes from an accessibility standpoint, emphasizing its potential as a user-centered design tool. With a more experimental approach, Virtanen (2019) develops an indoor accessibility simulator validated with users with reduced mobility, focusing on wheelchair use.

These studies demonstrate the value of immersive experiences in evaluating architectural barriers and space accessibility. However, none provide a tool for VR exploration of an environment directly from a 2D floor plan with automatic or semi-automatic navigation.

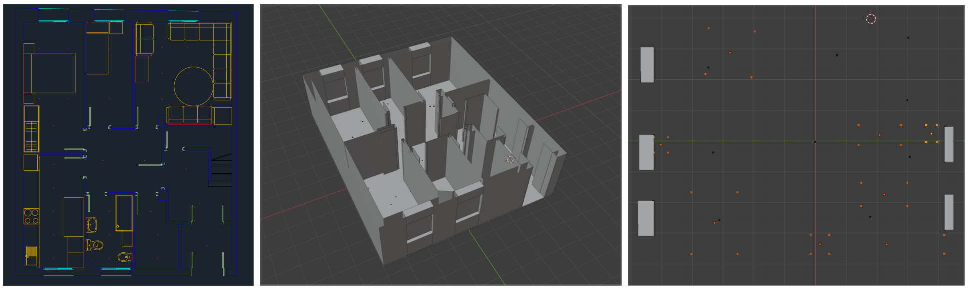
Indeed, commercial solutions are available for the automatic reconstruction of 3D models from 2D floor plans. They are mainly focused on reducing manual modeling effort, but do not consider accessibility or immersive experiences. Nevertheless, they can serve as a base or inspiration for building a system like the one we propose. For instance, commercial add-ons like WiseBIM (WiseBIM, 2024) offer efficient AI-based pipelines but remain tied to proprietary ecosystems (Autodesk Revit). In the open-source realm, FloorplanToBlender3D (Westberg, 2018) proposes a computer-vision–based workflow, though it lacks semantic integration.

Overall, existing approaches highlight both the potential and limitations of current solutions. Commercial platforms offer maturity but little accessibility focus, while academic prototypes provide insight but often lack integration and usability. Our work aims to bridge this gap by combining semi-automated 2D-to-3D reconstruction with immersive VR visualization, specifically tailored for accessibility assessment and participatory renovation design.

3 System Design

Figure 1 illustrates the workflow of our approach, from an architect's renovation project and the corresponding CAD drawings (before and after renovation) to the immersive VR experience.

The system consists of two core components, extrusion and VR scene generation, preceded by a preprocessing stage. Preprocessing adapts the architect's drawings to the input constraints of the subsequent stages, ensuring that 2D elements can be reliably identified. Extrusion, shown



(a) 2D floor plan

(b) 3D model from CAD drawings

(c) Top-down view with floor removed, highlighting bounding boxes as furniture placeholders

Figure 2: Generation of a 3D apartment model from 2D floor plans, including furniture placement represented by bounding boxes and geometric centers.

as the green box in the diagram, automatically builds the 3D structure of the apartment from 2D CAD plans, generating walls, windows, and doors, and placing placeholders for furniture and lights. VR scene generation, shown as the blue box, uses a VR rendering engine to transform the 3D description into an immersive stereoscopic environment that users can explore.

The three stages of the pipeline are loosely coupled, meaning that the technologies used in our prototype for each stage can be easily replaced by alternative solutions. They can be deployed automatically from the VR interface, provided that the input CAD plans supplied to the Extrusion stage satisfy the following constraints:

- Files must be provided in DXF format, an open CAD standard.
- Separate layers must be used for walls, doors, windows, and lights.
- Each furniture item must be placed in its own layer (one layer per item).
- An additional layer must specify furniture orientation.

The preprocessing stage ensures compliance with these constraints, adapting the architect's work for the system. In our case, we built the prototype in collaboration with architects working with Autodesk AutoCAD, a proprietary tool widely adopted in architecture. Their renovation projects were stored in the DWG format, with the architects making an effort to meet most of the required constraints, except that all furniture was placed in the same layer and organized as separate blocks. Our preprocessing script generates individual layers for each furniture item and exports the result to DXF.

Extrusion

Our implementation of the Extrusion component leverages Blender, a widely used open-source 3D modeling tool. The modeling process is automated through Python scripts using Blender's `bpy` library, which provides control over key operations such as curve-to-mesh conversion, extrusion, object manipulation, and primitive generation. Auxiliary libraries OpenCV and NumPy are also employed for computing rotated bounding boxes, which are essential for correctly measuring and orienting objects.

This stage produces two `.blend` files representing the apartment in 3D before and after renovation. These files include walls, doors, and windows extruded from 2D curves, as well as generated floor and ceiling surfaces, and correctly positioned and oriented placeholders for furniture and light sources.

Figure 2 illustrates the Blender-based Extrusion stage of our pipeline, which converts 2D floor plans into 3D geometry. Alongside the original CAD drawing, we provide both a perspective

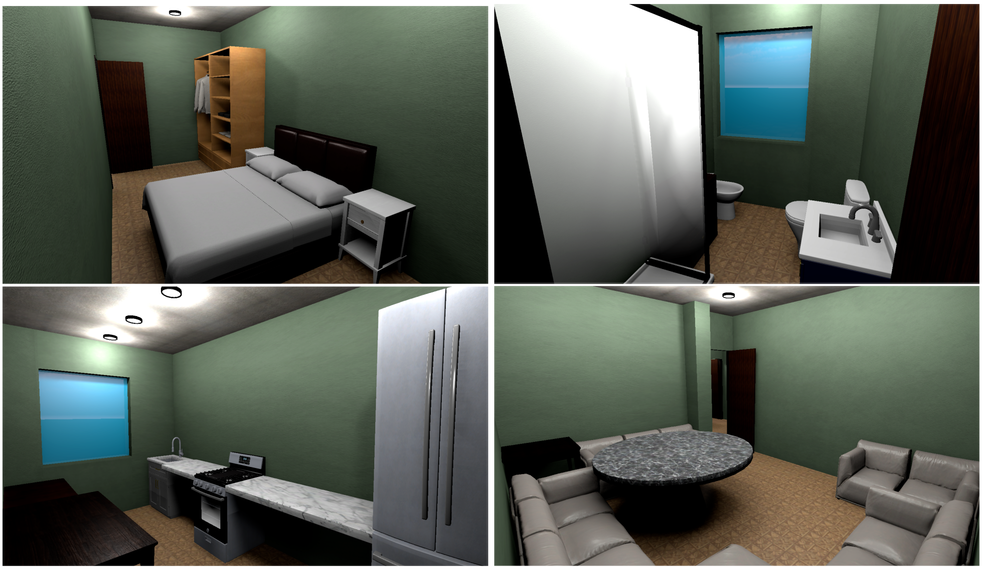


Figure 3: Views of an apartment rendered in VR, built in 3D from 2D floor plans.

view and a top-down view of the reconstructed model, highlighting furniture placement using bounding boxes and geometric centers.

VR scene generation

The VR scene generation stage in our implementation was developed in Unity, a graphics engine for interactive applications, using the XR Interaction Toolkit with support for the OpenXR standard.

In this stage, materials are applied, furniture and lights are placed, interactive behaviors are programmed, and a user interface is implemented to navigate and switch between the two apartment states. The system detects collisions with architectural elements and furnishings by adapting the avatar's collision boundaries to whether the user is walking or using a wheelchair.

The aspects of UI and VR interaction are discussed in Section 4. Regarding scene generation, the 3D input from the extrusion stage is automatically processed in Unity to enrich the environment and produce an immersive VR visualization. The processing in this stage can be summarized as follows:

- Walls: a predefined material is applied, and collision meshes are added to enable physical interaction within the scene.
- Windows: divided into three sections (top, bottom, and glass panel). Opaque parts receive a standard material, while the glass panel is assigned a transparent material simulating glass. Collision meshes are also included.
- Doors: assigned a base material and physical components to allow realistic opening through physics simulation. For VR interaction, Unity XR components enable natural push–pull interactions using the controllers.
- Furniture: a placement script interprets the metadata from the extrusion stage, selects an appropriate prefab from the furniture library, and places it at the specified location with an associated collision mesh.
- Lighting: point lights are instantiated at the locations indicated in the plans and attached to the ceiling, providing localized illumination. Global lighting is completed with a pre-

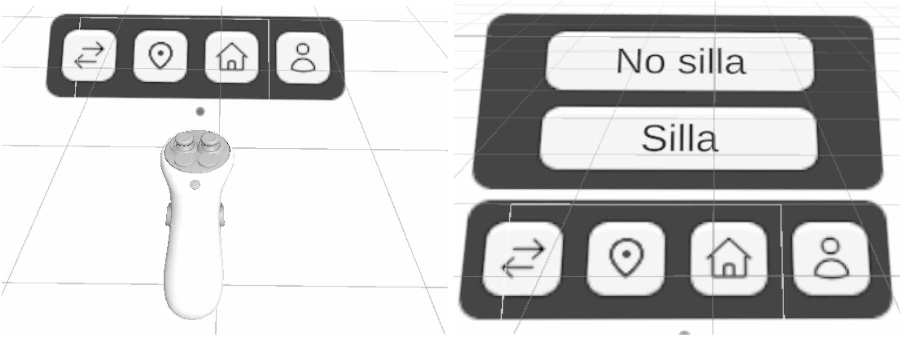
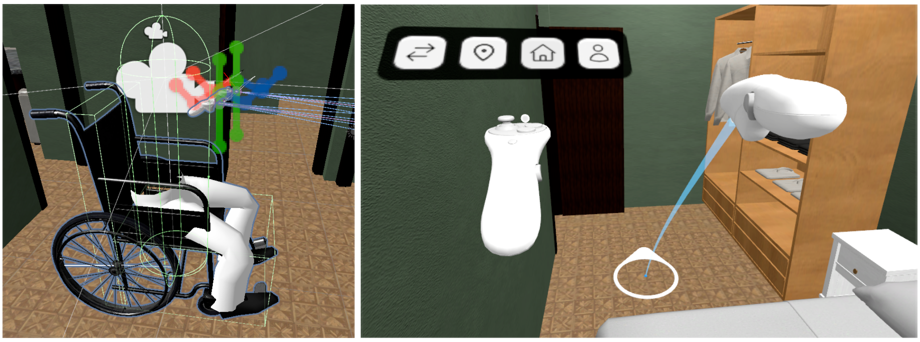


Figure 4: Wrist-mounted user interface supporting VR navigation with two exploration modes: walking and wheelchair.



(a) Wheelchair navigation mode

(b) Teleportation target selection

Figure 5: Implemented UX features include wheelchair navigation and teleportation.

defined directional light simulating daylight entering through windows, and ambient light to avoid completely dark areas.

Figure 3 shows examples of different rooms from an apartment rendered in VR with Unity, based on the CAD drawings processed through the extrusion stage.

4 VR User Interaction

The user interface allows navigation through the apartment using a wrist-mounted menu. As shown in Figure 4, this menu provides four main functions:

State switch: toggles between the two apartment states (pre- and post-renovation).

Reset position: restores the user's location in the virtual environment, useful to address calibration problems or mobility constraints.

Rebuild: opens a submenu with options to regenerate the 3D model in Blender and relaunch the integration scripts into the active Unity scene.

Mobility mode: opens a submenu to choose between walking or wheelchair navigation (shown in the right screenshot of Figure 4). Figure 5 shows the user avatar employed in the wheelchair navigation mode.

Beyond those UI controls, two navigation systems have been implemented to support flexible exploration, subject to device capabilities: Teleportation, where the user points a ray to the

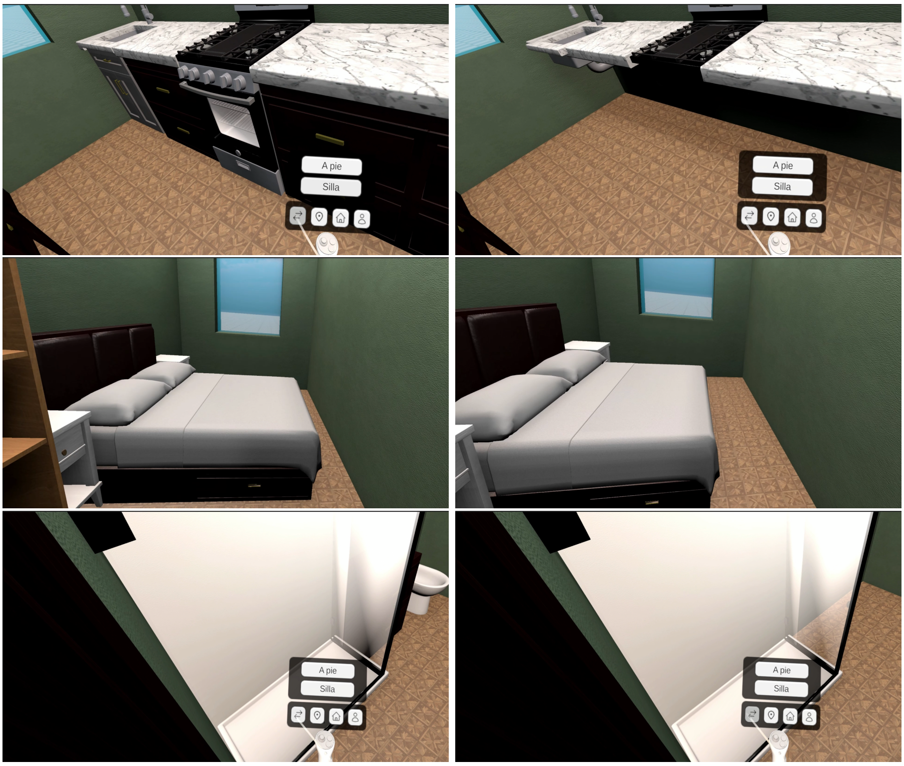


Figure 6: Visualization of selected areas of the apartment before and after the renovation.

floor with the right joystick to mark a destination and is instantly relocated there; and Smooth locomotion, where the left joystick enables continuous movement within the environment. The screenshot in Figure 5a was capture while the user selected a teleportation target.

5 Prototype Evaluation

The tests carried out during development were performed with the HTC Vive Pro 2 headset, using the real floor plans of one of the apartments renovated by COGAMI [1]. The different iterations of the prototype were validated by COGAMI technical staff, although validation tests with end users have not yet been conducted. Figure 6 shows examples of the apartment used as a case study, illustrating the before-and-after renovation states. The project's source code is publicly available for reference and reuse at *https://github.com/TsolidarioFG/2025-COGAMI*.

6 Conclusions and Future Work

The constructed VR system allows for an intuitive interactive analysis of a apartment's accessibility based on its floor plans. The state-change functionality enables direct comparison between pre- and post-renovation versions. The ability to navigate in wheelchair mode highlights spatial limitations, supporting decision-making, although modeling realistic wheelchair han-

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[1] COGAMI, the Galician Confederation of People with Disabilities (*https://www.cogami.gal*), is an organization that advocates for the full inclusion of people with disabilities in all areas of society. Among its activities, it provides logistical and financial support for housing renovations for people with disabilities.

dling (movement, turning, etc.) remains as future work. Incorporating a higher degree of realism in the visualization has also been postponed for the near future (improved lighting, better materials, etc.), as well as the possibility of automatically downloading 3D models from furniture and bathroom fixture manufacturers, to avoid being limited to the preconfigured models in the system. A further objective for future work is to replace Unity with Godot as the VR engine, thus ensuring the system remains fully open and unrestricted.

7 Acknowledgements

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