Walking the Digital Street: A VR Tool for Assessing Urban Walkability

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Abstract

This paper presents a Virtual Reality (VR) prototype designed to evaluate walkability in urban environments. The system allows participants to navigate a digitally reconstructed urban area at human scale, observing how spatial design influences comfort, accessibility, and pedestrian movement. Within the immersive environment, users can walk, experience, and annotate locations they perceive as safe, pleasant, or problematic. The prototype records positional data, hesitation points, and verbal feedback to identify positive and negative impressions and reactions. Through this approach, the study demonstrates how embodied exploration in VR can reveal experiential aspects of walkability often overlooked in traditional planning tools. This paper highlights the potential of VR as a participatory and analytical method for informing inclusive and human-centered urban design.

CCS Concepts

• **Human-centered computing → Virtual reality**; *Interaction design*; *Participatory design*; *User studies*; • **Applied computing →** *Architecture (urban planning).*

Keywords

Virtual Reality, Walkability, Urban Planning, Interaction Design

1 Introduction

The current practice of urban planning often uses two-dimensional maps, static three-dimensional drawings, or technical blueprints to visualize urban designs [12, 18, 20]. While these representations are valuable for understanding spatial layouts, they fall short in capturing the embodied perspective of pedestrians as they move through space. In response to the rapid urbanisation trend in recent years, the field of urban planning has adopted multiple tools and methods to improve the quality of urban design. Among those tools, Virtual Reality (VR) has the potential to be helpful in the urban design process [6, 11]. VR allows urban design to be reviewed from multiple perspectives, including overhead views, pedestrian views, and free exploration of the urban area [4].

Walkability is a key consideration in urban planning, shaped by infrastructure, land use, and socio-economic factors. As cities face increasing urbanization and sustainability challenges, promoting walkable environments has become essential for reducing car dependency and fostering healthier, more sustainable communities [7]. Research links walkability to public health benefits, including increased physical activity and improved mental well-being [9]. However, traditional urban planning methods often focus on quantitative metrics, overlooking subjective aspects such as senses of safety, comfort, and aesthetics [3, 13, 15, 17]. This gap underscores the need for human-centric approaches that integrate pedestrian experiences into planning. VR offers a solution by enabling immersive visualization and stakeholder engagement, allowing planners to assess walkability beyond static models[5, 14]. Integrating VR into urban design has the potential to support decision-making, bridging the gap between objective planning metrics and the experiential quality of walkable environments.

This research integrates VR technology to provide planners and stakeholders with immersive, real-time simulations of urban environments, allowing for interactive evaluation and modification of design proposals. VR can enhance spatial understanding and facilitate informed feedback, fostering collaborative decision-making, especially with non-professional stakeholders.

2 VR Prototype Implementation and Features

Our prototype is a VR system developed to assess walkability in an urban planning context. We built the virtual environment using Unity 3D in combination with the Virtual Reality Toolkit (VRTK), which provides a robust framework for common VR interactions and navigation. The prototype runs on a single high-performance PC, which is tethered via USB-C link to a Meta Quest 3 head-mounted display. This setup delivers a smooth VR experience at 60 frames per second (FPS) on the Quest 3 headset. Users wear the Quest 3 and hold its hand controllers, which enable intuitive movement and interaction within the virtual environment. The prototype is setup as ready-to-use for future integration with future data input.

Virtual Environment Design: The current prototype covers an area of approximately 650 × 850 meters. It is constructed using 3D models from the Unity Asset Store to represent typical urban elements, such as walkways and sidewalks, street layouts, greenery

AlpCHI 2026,

ACM ISBN 978-x-xxxx-xxxx-x/YYYY/MM
https://doi.org/10.1145/nnnnnnn.nnnnnnn

and trees, building facades, public plazas, benches, pedestrian crossings, and other infrastructure relevant to walkability. The scene is visually immersive and lifelike, allowing participants to feel as if they are navigating a real city block. Within this environment, users can walk using controller inputs, look around in 360°, and encounter various features that affect the pedestrian experience, such as textured pavements or shade from trees. The scale of all objects and distances is true to life, preserving the actual spatial proportions, unlike scaled-down physical models or 2D maps. Participants in the VR can see and feel how wide a sidewalk is, how far apart safe crossing points are, or how good the greenery on the street is—factors that are critical for assessing walkability and comfort [8, 10].

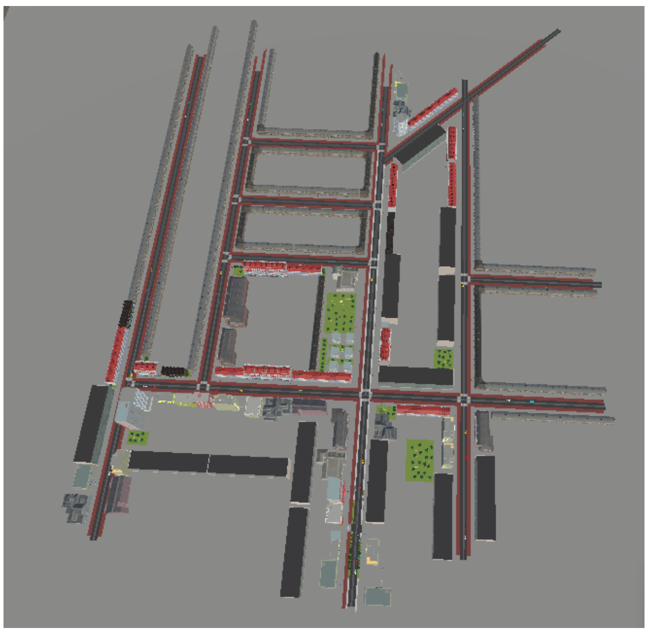

Figure 1: VR urban environment

Interactive Features: The prototype includes interactive elements that encourage users to engage dynamically with the scene. Using the Quest 3 controllers, participants can perform actions such as pointing, selecting and editing virtual objects. They might also encounter simple scripted events – for example, a pedestrian traffic light that changes when approached, or ambient sounds that react to their presence – to enrich the realism of the experience. These interactions not only make the simulation more engaging but also allow the system to capture how users behave and respond in the environment. For instance, if a participant stops to inspect a particular sign or struggles to find a safe crossing, those moments can be logged by the system (as described below). By providing an experiential understanding of space, the VR prototype allows users to feel the effectiveness of design features: are pathways intuitive or confusing? Does the placement of trees and street furniture create a welcoming atmosphere or obstruct the walkway? Such qualitative impressions are difficult to obtain from static blueprints, but they emerge naturally when users explore the design in an immersive way.

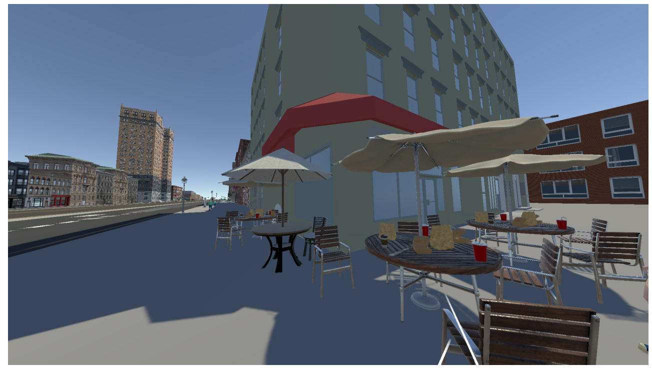

Figure 2: First-person view in VR prototype

3 Qualitative Data Collection Methods

To evaluate the VR prototype's usefulness and gather user feedback, we employed multiple qualitative data collection methods around the VR experience. Pre-interaction interviews were conducted with each participant before they entered VR. In these brief interviews, participants were asked about their expectations, prior experience with VR or urban design tools, and what they anticipated regarding the walkability of the upcoming virtual environment. This helped establish a baseline for their initial attitudes and any concerns or interest areas they might have.

Each participant then used the VR prototype to explore the virtual urban area freely, typically for a set session (for example, 10–15 minutes of exploration). During this VR session, a think-aloud protocol was used to capture real-time reactions. Participants were encouraged to verbalize their thoughts continuously as they navigated the virtual streets – describing what they were looking at, thinking, feeling, and any immediate feedback on the environment's walkability features. In a think-aloud session, users might say things like "This street feels a bit narrow here" or "I notice there's a crosswalk, I'll try using it," or even express confusion or delight at certain features. Such concurrent verbalization offers rich insight into the participant's cognitive and emotional responses. Vocalizing their stream of thought can help to understand why a participant might hesitate at a corner, what draws their attention, or how they decide their route, rather than only seeing the end results of their actions. All verbal comments were recorded for further analysis.

After the VR exploration, post-interaction interviews were carried out. In these, we asked participants to reflect on the experience, elaborate on any difficulties or interesting points noted during the session, and give overall usability feedback on the VR system. We also inquired about their perception of the virtual environment's walkability: for example, Which areas felt most pedestrian-friendly or unfriendly? Did anything in the design make walking easier or more difficult? These semi-structured interviews provided more in-depth qualitative feedback, allowing participants to summarize their impressions once they had removed the headset. The combination of the immediate think-aloud comments and the reflective pre/post interviews gives a comprehensive understanding of user experience. Together, these qualitative data streams help identify both the strengths of the VR prototype (e.g. features participants found useful or realistic) and areas for improvement (e.g. any aspects that caused confusion or discomfort). This integrated approach aligns with recommended practices in usability research, where observational data and self-reported data are used to evaluate a system's effectiveness[16, 19]. All insights gathered through these methods will inform future iterations of the VR tool, ensuring that it better meets the needs of urban planners and other stakeholders in assessing walkability[1].

4 Data Logging and Quantitative Metrics

In addition to qualitative feedback, the VR prototype records detailed quantitative data from each session. These automated logs provide objective measures of how participants moved and acted in the virtual environment, which can be analyzed alongside the qualitative observations. The raw data captured by the system includes:

Positional Tracking: The participant's coordinates within the VR environment are recorded at a frequency of 1 Hz (once per second). This yields a timestamped path of where the user walked over time. It allows us to later reconstruct their exact route through the virtual city and measure metrics like total distance travelled, the total area covered, or areas visited frequently.

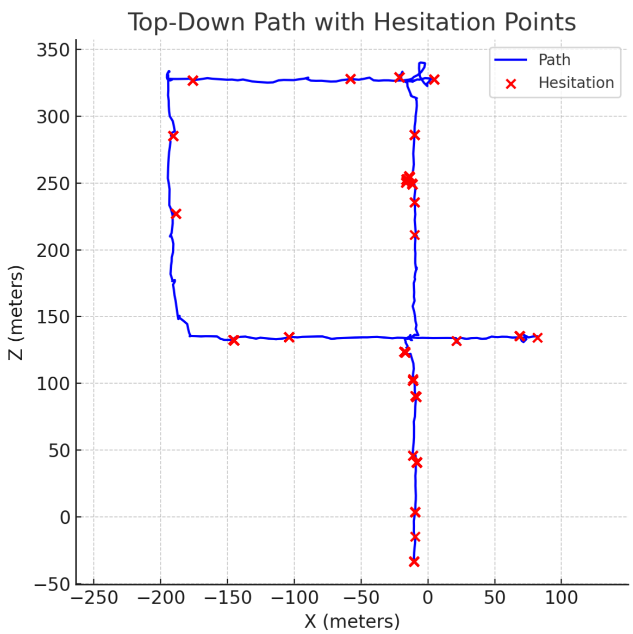

Figure 3: Pathway and Hesitation Points Log

Hesitation Points: The system is programmed to detect moments of hesitation or pauses. If the participant remains within a small area (not moving more than 2 meters) for a duration of 5 seconds or more, that location is logged as a hesitation point. These points might indicate places where the user was uncertain how to proceed, found something interesting or confusing, or had to make a navigation decision. By reviewing where hesitation points occur, we can pinpoint design elements that may need attention – for example, a complex intersection where users pause might suggest poor wayfinding cues.

Interactions and Actions: Every time the participant performs an interaction using the controllers (such as pressing a button or editing an object), the system logs the action. The log includes the type of interaction and the object or subject of that interaction. The total count of interactions and a breakdown by type serve as quantitative indicators of engagement levels and how users are utilizing the environment's features. A higher number of interactions might indicate that the environment affords many opportunities for engagement, whereas fewer interactions might mean the user simply walked without engaging, which reflect either an effortless navigation or a lack of interactive features.

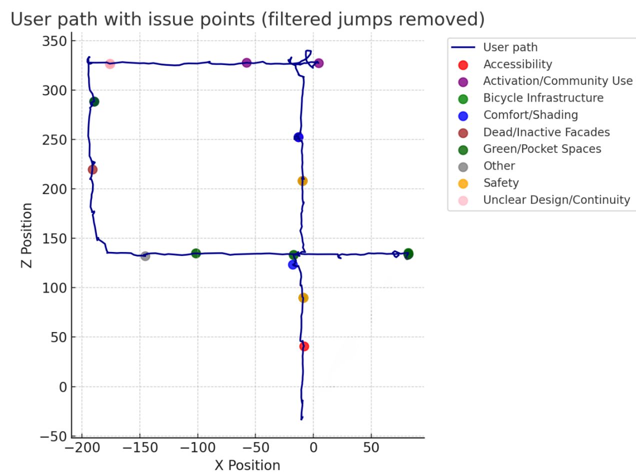

Figure 4: Voice Notes and Annotations Logs

Voice Notes and Annotations: Participants have the option to make voice notes during the VR session by using a controller button to record a short verbal memo. When a voice note is created, the system saves the audio clip and also logs the exact location, as well as a snapshot of what the participant was looking at in that moment. This feature enables participants to record a voice note of a specific location within the VR urban area. For example, a user might say, "This alley feels unsafe," as a voice note; the system would then store that comment along with a picture of the alley view and its coordinates. These annotations are valuable for correlating subjective impressions with specific places in the virtual environment.

All the above data are time-synchronized, which means we can replay a session and see, at any given second, where the participant was, what they were looking at, and what actions or comments they made. This comprehensive logging supports a detailed quantitative analysis of user behavior. For instance, we can map all participants' paths to identify which routes were most commonly taken, or we can analyze how long on average users hesitated at a particular location. We can also quantitatively compare different design scenarios within the VR , if the environment is modified, by looking at changes in these metrics. Ultimately, these data help in measuring walkability in a more evidence-based way – not just relying on what users say, but also how they actually move and react in the space.

5 Discussion

A key contribution of this work is demonstrating that immersive VR can better support stakeholder engagement than conventional planning tools, particularly for audiences unfamiliar with technical drawings. VR provides an intuitive, first-person experience of the urban environment, allowing participants to perceive spatial relationships, scale, and movement as they would in real life. This makes it especially valuable for gathering meaningful community feedback on walkability and design proposals, as it lowers the cognitive barrier for non-experts to understand, evaluate, and contribute to planning discussions. Below we highlight some major differences and benefits of using VR for walkability assessments:

Immersive, First-Person Perspective: VR allows stakeholders to experience the environment from a pedestrian's eye view, providing a true sense of scale and spatial relationships. Users can gauge how wide a sidewalk feels, how tall buildings or trees appear around them, and how far distances are—things that static maps or miniature models cannot convey accurately. This first-person experience helps planners identify design flaws or discomforts early in the process. In VR, an urban planner can virtually "walk" in someone's shoes and identify issues that might be overlooked in a drawing. By integrating VR into walkability assessments, potential problems can be discovered and addressed before actual construction, reducing costly modifications later.

Interactive Exploration and Dynamic Scenarios: Unlike a 2D drawing or a static 3D rendering, a VR simulation is fully interactive and can emulate dynamic real-world conditions. Users in VR can choose their routes, interact with objects, and even experience changing scenarios on the fly. For example, the VR environment can be adjusted to simulate different lighting conditions, weather, or varying pedestrian traffic levels to observe how these factors impact the walking experience. Planners can toggle between design alternatives instantly—such as testing a street with and without a bike lane or with different sidewalk widths—and immediately observe the impact on walkability. This flexibility is hard to achieve with physical models or paper plans, and even on a standard 2D screen. VR's dynamic simulation capability helps ensure that pedestrian-friendly elements are effective across multiple contexts and stress conditions.

Enhanced Communication and Engagement: VR serves as a universal visualization tool that can bridge the gap between technical experts and the general public. In traditional planning meetings, community members may struggle to understand complex plan drawings or GIS maps, which limits their ability to provide input. In contrast, handing someone a VR headset and letting them walk through a proposed design can immediately convey the look and feel of the planned urban environment. This makes urban planning more inclusive—everyone can experience and comment on the design in a tangible way, without needing specialised knowledge to interpret it. Studies have noted that traditional processes often receive limited public feedback because many people lack the expertise to analyse static maps or architectural blueprints [2]. VR removes that barrier by allowing people to see the prospective changes for themselves. This not only improves feedback quality but also helps to generate public support or identify concerns early on. Overall, the immersive visualization fosters more effective communication among planners, designers, and community stakeholders, aligning everyone's understanding of the project.

In summary, VR enriches the urban planning toolkit by combining the realism of field observations with the control of a simulation environment. It enables trial-and-error exploration of design options in a safe, cost-effective manner, and capture insights into pedestrian experience that traditional methods might miss. By comparing VR with conventional techniques, our paper underlines how even small design decisions can be felt by users—an awareness that planners can leverage to create more walkable, livable cities.

6 Conclusion

This paper has presented a VR-based approach for walkability assessment in urban planning, detailing the implementation of an interactive virtual environment and discussing the data collected from user interactions. The prototype demonstrates the feasibility of utilising consumer VR technology (such as Meta Quest 3 and Unity) to enable both experts and everyday users to step into a future urban design and evaluate its pedestrian-friendliness firsthand. Early qualitative feedback indicates that experiencing a design in VR can reveal subtle insights – such as points of confusion, feelings of safety or comfort, and navigational preferences – that complement traditional analysis. Quantitatively, the system's logging of movement patterns and interactions provides an evidence-based measure of how walkable a space is, beyond just static metrics or indices.

Moving forward, integrating these VR-derived insights into the urban planning process could significantly enhance decision-making. City planners could use VR simulations not only to test and refine designs for optimal walkability but also to communicate proposals to the public in a more engaging way. While VR is not intended to completely replace traditional methods, it serves as a powerful experiential evaluation tool that enhances the planner's ability to anticipate human responses to an environment. Future work will focus on refining the prototype; for instance, by increasing realism, adding more interactive scenarios, improving ease of use, and conducting more extensive user studies. Ultimately, the goal is to contribute to a set of best practices for utilising VR in urban design, making urban planning more participatory, data-informed, and attuned to the lived experiences of pedestrians.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101034328.

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