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Walking With and Walking Through: Assessing Urban Design From Streets to Virtual Reality

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Abstract

Urban planners are increasingly exploring innovative methods to promote walkable cities, but traditional stakeholder engagement tools often fall short in fully capturing the pedestrian experience or facilitating inclusive urban design. This study investigates the use of virtual reality (VR) as a digital tool to bridge this gap and support planning for urban walkability. We began by conducting a series of go-along interviews with residents in Eindhoven, the Netherlands, to identify factors influencing local walkability. Next, we built an immersive VR urban environment. To ensure the digital tool reflected local lived experiences, we used interview insights to build the VR scenario, which featured targeted walkability factors identified from the interviews, such as lighting, greenery, and crossings. Subsequently, urban planning professionals were recruited to use the tool as a means of visualization to assess and reflect on the VR tool and its potential for urban design. Results indicate that the immersive environment offers an alternative method of visualization, revealing qualitative insights about urban design that differ from the quantitative data commonly found in conventional methods. The professionals reported that the VR tool allowed them to experience and assess urban design firsthand, while also highlighting its potential to effectively communicate design proposals to a broad range of stakeholders. The study concludes that VR has the potential to transform urban planning by providing an interactive urban design method, enabling inclusive urban design, and comprehensively addressing urban design walkability challenges.

Keywords

qualitative methods; urban design evaluation; urban planning; virtual reality; walkability assessment

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1. Introduction

Urbanization, climate change, and public health concerns have increasingly positioned walkability as a central objective in contemporary urban planning. Walkable environments are associated with reduced car dependency, lower carbon emissions, improved public health, and stronger social cohesion (Blečić et al., 2020; Forsyth, 2015; Southworth, 2005). However, walkability is no longer assessed solely by the presence of pedestrian infrastructure. Instead, it is increasingly conceptualized as a multidimensional construct also shaped by subjective measures such as accessibility, safety, comfort, legibility, and aesthetic qualities that influence how pedestrians experience urban environments in everyday life (Blečić et al., 2020; Forsyth, 2015; Hynes & Seoighthe, 2018). Despite this conceptual advancement, assessing walkability remains challenging. Traditional urban planning approaches typically rely on geographic information systems (GIS), objective walkability indices, and static design representations such as maps, drawings, and 3D renderings. While these tools effectively measure physical infrastructure and spatial connectivity, they often fail to capture the embodied and experiential dimensions of walking, including perceived safety, environmental comfort, and legibility. As a result, there remains a gap between what planners measure and how pedestrians actually experience urban space (Blečić et al., 2020; Forsyth, 2015; Hall & Ram, 2018).

To address this limitation, researchers have increasingly adopted human-centered methods such as in-situ observations, surveys, and physiological measurements to assess pedestrians' subjective perceptions of walkability. Go-along interviews, for example, allow researchers to capture real-time pedestrian experiences within the built environment, revealing micro-scale walkability challenges that are often overlooked in aggregated spatial analysis (Carpiano, 2009). However, while such methods provide valuable insights into existing environments, they are limited in their ability to evaluate proposed or future urban designs before implementation, highlighting the need for tools that can test design concepts before construction. Recent advances in immersive technologies, particularly virtual reality (VR), offer new opportunities for walkability assessment. VR enables first-person, interactive exploration of simulated urban environments, allowing users to experience spatial layouts, evaluate pedestrian infrastructure, and identify walkability issues prior to construction. This immersive capability has positioned VR as a promising tool for urban planning, participatory design, and stakeholder engagement (Nakamura, 2021). Nevertheless, existing VR-based urban planning studies frequently emphasize technological feasibility, visualization, or stakeholder engagement rather than systematically evaluating perceived walkability through immersive experiences, and there remains a lack of standardized protocols that link VR experiences to specific walkability attributes and outcomes (Birenboim et al., 2021; Nakamura, 2021).

This study addresses this gap by investigating how immersive VR can support walkability assessment and urban design evaluation through qualitative data analysis. Specifically, the research combines real-world pedestrian experiences with immersive simulation through a two-part mixed-method approach. First, in-situ go-along interviews were conducted with residents in Eindhoven to identify key walkability dimensions and lived pedestrian experiences. Second, an immersive VR prototype was developed and evaluated with urban planning professionals to examine how immersive environments support walkability assessment and design improvement.

The findings suggest that immersive VR can help participants identify selected walkability issues related to safety, comfort, legibility, and aesthetics that may be less visible in traditional planning representations.

Participants also highlighted VR's potential to support stakeholder communication, participatory design, and iterative urban planning processes. By linking real-world pedestrian experiences with immersive simulation, this research contributes to emerging human-centered approaches in urban planning and positions VR as a complementary tool for exploratory walkability assessment.

This article contributes to the field in three ways. First, it provides empirical insights into pedestrian experiences through in-situ go-along interviews. Second, it suggests how immersive VR can support walkability evaluation and design improvement. Third, it proposes a combined methodological approach that integrates lived pedestrian experience with immersive simulation to support human-centered urban planning.

2. Literature Review

2.1. Walkability in Urban Planning

Walkability in an urban context is defined by several important attributes: connectivity, integration with other travel modes, safety, quality of the path, and its context (Southworth, 2005). In the context of increasing global urbanization, climate change, and public health challenges, promoting walkable environments has become an essential mechanism for reducing car dependency, mitigating carbon emissions, and supporting healthier, more socially cohesive communities (Blečić et al., 2020). Walkability is no longer viewed as a basic provision of pedestrian infrastructure, such as installing concrete sidewalks. To effectively design for walkability in modern urban planning, it is necessary to define its multidimensional aspects, establish indicators, and deploy measurement methodologies that capture both the objective physical environment and the subjective human experience.

Computational approaches to pedestrian modelling provide an important basis for assessing spatial accessibility and pedestrian movement. Sevtsuk and Kalvo (2025), for example, present urban network analysis as a framework for modelling pedestrian activity in cities by examining how urban form and accessibility influence pedestrian travel. Such approaches are valuable for evaluating pedestrian flows, network structure, and accessibility in both existing and planned urban environments. However, they primarily address spatial and quantitative dimensions of walkability, while perceptual and experiential factors such as perceived safety, comfort, legibility, and atmosphere remain more difficult to capture through modelling alone. Therefore, the present study positions VR not as a replacement for computational walkability modelling, but as a complementary method for examining pedestrian-scale and experiential dimensions of walkability.

Climate and microclimate conditions influence walkability by shaping pedestrians' thermal comfort and environmental experience, including shade, wind exposure, and temperature variation (Kim et al., 2018; Vasilikou & Nikolopoulou, 2020). Greenery, including street trees and parks, can also improve comfort and walking experience.

Connectivity refers to the density and directness of pedestrian networks, including fine-grained street grids and intersection density, which facilitate route choice and reduce travel time on foot (Blečić et al., 2020; Forsyth, 2015). Complementing connectivity, integration with other travel modes reflects how well pedestrian

routes connect with public transport and cycling infrastructure, supporting first- and last-mile access (Hynes & Seoighthe, 2018; Telega et al., 2021).

Safety is a foundational attribute, including traffic safety, perceived safety, lighting, and surveillance, all of which influence pedestrians' comfort and willingness to walk (Hynes & Seoighthe, 2018). Path quality, including surface condition, width, obstructions, continuity, shade, and weather resilience, directly affects the ease and pleasure of walking.

Perceived safety and comfort in public space are shaped by gendered walking experiences. Research shows that women's movement through public space is influenced by perceived risk, visibility, lighting, social surveillance, and route choice (Koskela, 1997; Loukaitou-Sideris, 2005). Women-led safety assessments, therefore, offer a relevant participatory approach for identifying how safe or unsafe public environments feel (Whitzman et al., 2009). These studies highlight that walkability is not only determined by physical infrastructure, but also by how different users perceive, access, and negotiate public space.

Finally, path context, such as the spatial and cultural character of a neighborhood, including aesthetic attributes and pedestrian-scale design, frames how walkability is experienced and valued (Morales-Flores & Marmolejo-Duarte, 2021). The "15-minute city" concept similarly emphasizes that daily needs should be reachable within short walking or cycling trips, and empirical work operationalizes this idea by evaluating walking accessibility to everyday services such as grocery stores and schools (Allam et al., 2022). This aligns with broader evidence that walking accessibility improves when multiple everyday destinations are reachable within short walking distances.

These concepts turn broad ideas into measurable indicators. In urban planning, indicators are typically organized into three data types: objective measures, evaluative subjective judgments, and hedonic states (Blečić et al., 2020). Objective measures are observable, countable data collected with standard procedures, such as street width, sidewalk area, or traffic counts (Blečić et al., 2020). Evaluative judgments capture people's subjective assessments of environmental quality, for example perceived safety or perceived maintenance. Hedonic states describe how people feel in a place, such as emotion, stress levels, or enjoyment while walking. Data collection methods typically include direct on-site audits and surveys, as well as external data from other sources, spanning multiple spatial scales to capture the walking experience.

2.2. Methods for Assessing Walkability

In the context of global urbanization and public health challenges, walkability has evolved from the basic provision of pedestrian infrastructure within car-centric planning into a multidimensional construct essential for sustainable urban mobility (Blečić et al., 2020; Southworth, 2005). Contemporary urban planning defines walkability through the complex interplay of physical geometries, psychological perceptions, and microclimatic conditions, often conceptualized through the "5Ds" of urban design: density, diversity, design, destination accessibility, and distance to transit (Ewing & Handy, 2009). A critical insight in recent literature is the frequent divergence between objective walkability, measured by spatial algorithms, and subjective walkability, assessed through lived pedestrian subjective experiences (Morales-Flores & Marmolejo-Duarte, 2021).

The evolution of these methodologies reflects a broader shift from functionalist engineering approaches towards human-centered modelling. Traditionally, tools such as Walk Score and GIS-based indices have been used to evaluate geometric capacity and network efficiency. While useful for baseline spatial analysis, these macro-level tools often fail to capture human-scale realities and experiential quality (Blečić et al., 2020; Hall & Ram, 2018).

Consequently, walkability assessment research has increasingly moved towards dynamic and predictive models that synthesize spatial data with human behavior. Immersive spatial computing, including VR, participatory co-design, and urban digital twins, represents emerging approaches for walkability assessment (Dane et al., 2024). This synthesis of static measurement and dynamic, human-centered simulation enables urban planners to better understand pedestrian experience and design more walkable cities.

2.3. VR in Urban Planning and Design

As walkability research increasingly emphasizes subjective pedestrian experience, urban planning tools are shifting from static representations toward more immersive forms of spatial evaluation. Traditional tools such as 2D maps, architectural drawings, and 3D renderings are useful for communicating spatial form and infrastructure, but they often struggle to represent movement, scale, environmental variation, and the lived experience of walking. VR and associated immersive technologies address some of these limitations by enabling first-person, embodied exploration of simulated urban environments. Schewenius and Wallhagen (2024), for example, show that immersive formats can direct attention to spatial details, topography, volume, and lighting conditions that may be less apparent in conventional plans, while also supporting a stronger sense of presence.

Recent studies have explored different ways of making VR more usable and accessible in urban planning. Rzeszewski and Orylski (2021) evaluated WebXR visualizations and showed that interactive 3D environments can be accessed through standard web browsers, reducing dependence on specialized software or heavy gaming engines. Oselinsky et al. (2023) demonstrated the feasibility of walking in modifiable VR environments, showing how specific design variables, such as street trees, can be tested in relation to walking experience and navigation. Together, these studies suggest that VR can support controlled and repeatable assessment of selected urban design conditions before implementation.

VR has also been used to support participatory planning and co-design. Dane et al. (2024) and Evers et al. (2023) developed immersive approaches that allow citizens to evaluate future public-space scenarios through visual, experiential, and interactive engagement. Their work on CoHeSIVE showed that participants could assess design attributes such as trees, benches, and lampposts in a more intuitive way than through conventional drawings (Dane et al., 2024; Evers et al., 2023). More recent work on co-located VR, such as Akkers et al. (2025), further suggests that shared immersive environments can support communication and collaborative decision-making, although session duration, comfort, and fatigue remain important considerations.

2.4. Research Gap

Despite the rapid emergence of VR as a tool for immersive urban analysis, a gap remains between what walkability indices measure and how pedestrians actually experience urban space. Traditional GIS-based

walkability metrics (e.g., Walk Score and related 3D/5D frameworks) quantify geometry and connectivity but often omit perceptual, social, and affective dimensions, such as perceived safety, comfort, social interaction opportunities, and aesthetic experience, that influence actual walking behavior and place satisfaction (Hall & Ram, 2018). This disconnect limits planners' ability to predict real-world walking patterns and to design interventions that improve social interaction and psychological well-being in public spaces. Recent work explicitly critiques geometry-centric measures and calls for integrating perceptual data, social indicators, and health outcomes into walkability assessments (Gorrini et al., 2023; Telega et al., 2021).

VR offers a promising approach by enabling controlled, immersive, and repeatable evaluation of pedestrian experiences. However, most VR-based studies focus on technological feasibility or usability rather than structured walkability assessment frameworks. Limited research has examined standardized protocols combining immersive VR experiences with pre- and post-experience evaluation.

This gap highlights the need for research investigating how immersive first-person VR can systematically assess perceived walkability and support iterative urban design decisions.

2.5. Research Approach

To address the research gap, this mixed-method research consisted of two key components, as shown in Figure 1: go-along interviews with residents and an immersive VR experiment with urban planning professionals. The go-along interviews with participants aimed to collect qualitative, pedestrian-level data in Eindhoven, focusing on multiple walkability dimensions. Insights from go-along interviews informed the development of the VR prototype in later stages. All procedures were approved by relevant ethics boards and followed informed consent protocols.

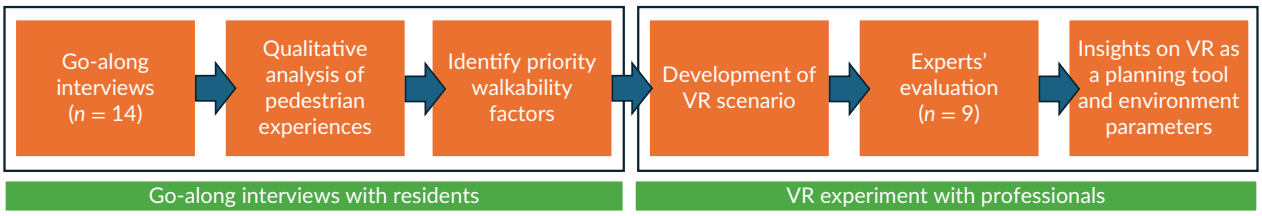


Figure 1. Mixed-method research design integrating go-along interviews with residents and VR evaluation with professionals.

3. Go-Along Interview

3.1. Study Design

Eindhoven was selected because its city center provides a complex context, where pedestrian routes, cycling infrastructure, public transport areas, and commercial streets intersect. These conditions made it suitable for examining everyday walkability issues, especially pedestrian–cyclist interactions, crossing clarity, safety, comfort, and path quality. While the methodological framework can be adapted to other cities, the findings are context-specific and may vary according to climate, mobility culture, infrastructure, safety norms, income levels, and access to digital tools.

Fourteen adult residents of Eindhoven (n = 14), including four female and ten male participants, who regularly walk in the city center, participated. Participants were recruited through the university mailing list and the researchers' personal networks. The inclusion criteria required participants to be adults, to live in or regularly visit Eindhoven, and to have regular experience walking in or around the city center. Rather than aiming for statistical representativeness, the go-along interviews were used to identify recurring walkability concerns and situated pedestrian experiences that could inform the later VR prototype and professional evaluation. The aim was not to generalize to all Eindhoven residents, but to capture situated pedestrian experiences that could reveal how walkability is perceived in everyday movement through the city. The interviews took place along a fixed route within the city center. The go-along interview route is shown in Figure 2. The route's familiarity enabled participants to relate their experiences to everyday activities, such as commuting and shopping, to specific environmental features. Each session followed a semi-structured guide covering pedestrian infrastructure, street design, climate, greenery, and public amenities. Interviews lasted approximately 15 to 25 minutes.



Figure 2. Go-along interview route in the study area.

Each walk was audio and video recorded using a chest-mounted camera and a handheld audio recorder. Participants discussed elements affecting their walking (e.g., surface quality, noise, safety). All identifiable information was removed to ensure confidentiality.

We conducted a thematic analysis of the transcripts from the collected audio data. The initial coding frame was developed deductively from walkability dimensions identified in the literature and prior stages of the

research, including safety, comfort, greenery, accessibility, transport connection, and technology use. During coding, additional codes were added inductively when participants raised issues that were not fully captured by the initial framework, such as cyclist–pedestrian conflict, perceived vulnerability at crossings, and the role of digital maps in reducing walking uncertainty. Two researchers independently reviewed the transcripts and then compared their coding through an inter-coder agreement discussion. Disagreements were resolved through consensus coding, and the final codes were organized into the main themes reported in Table 1. The chest-mounted video recordings were used as contextual material to clarify participants' references to specific places, objects, or street conditions during the walks.

3.2. Results of Go-Along Interviews

The go-along interview methodology functions as a diagnostic tool for examining pedestrian experience in situ. By moving through the environment alongside participants, the researcher avoids reliance on retrospective recall and captures immediate sensory, cognitive, and spatial responses. The study focused on six main areas of urban walkability that were identified in a previous study: walkability, climate, greenery, transportation, shopping, and technology (Pham et al., 2024). To provide a clear overview of the data, Table 1 outlines the specific problems or ideas participants raised during their walks, along with the number of people who mentioned each. Multiple themes could be identified within a single participant's response.

Table 1. Thematic distribution and participant frequencies.

Theme	Specific topic	Insights	Participant count
Walkability	Safety & Sidewalks	High-speed bikes are a danger to walkers. People want clearer lines between bike paths and sidewalks, flat roads, and better street lighting.	9 participants
Walkability	Look & Feel	People like the mix of old and new buildings. However, modern "tech" areas feel cold and need cozier, social spots.	7 participants
Walkability	Crowds	Busy areas like the train station and shopping streets can get stressful and too crowded on weekends.	2 participants
Climate	Weather & Comfort	People like the cool Dutch weather for walking. To deal with the cold, they just wear extra layers instead of driving.	4 participants
Greenery	Parks & Trees	People want more nature, like parks and community gardens, to help them relax.	5 participants
Transport	Buses & Waiting	Public transit is frustrating. Buses are late or infrequent, pushing people to rent e-bikes instead.	3 participants
Transport	Station Safety	Waiting for a bus in quiet or dark areas makes some people feel unsafe.	1 participant
Shopping	Distance Limits	People love having grocery stores close by. Most will only walk about 1.5 km (or 30 minutes round trip) before they choose to drive.	3 participants
Technology	Maps & Apps	Walkers rely on Google Maps to know exactly how long a trip will take, which makes walking feel easier.	2 participants
Technology	Health Goals	Step-tracking apps are a great way to push people to walk more every day.	1 participant

Walking is more than having a paved sidewalk; it is also about feeling safe and mentally comfortable (Saelens et al., 2003). The go-along interviews show that pedestrian safety in Eindhoven is shaped by the interaction between walking and cycling infrastructure. As shown in Table 1, safety and sidewalk conditions were the most frequently mentioned issue, raised by nine participants. Participants particularly emphasized the risk created by fast-moving bicycles and unclear boundaries between pedestrian paths and cycle lanes. Participant 1 noted that "the main challenge is the bike traffic; as a pedestrian, you really have to watch out when crossing the red cycle paths," while Participant 2 similarly stated that "the line between the sidewalk and the bike lane is a bit blurry." These comments suggest that walkability in this context depends not only on pedestrian infrastructure but also on clear spatial separation, legible crossings, and perceived safety.

Climate and greenery also emerged as important dimensions of walking comfort. Four participants discussed weather and comfort, while five participants referred to parks, trees, and greenery. Although several participants described the cool Dutch climate as supportive of walking, they also noted that wind exposure, open squares, and lack of shelter can reduce comfort. Green infrastructure was valued not only for visual quality, but also for its calming and restorative effects. Participants described trees, parks, and green spaces as making routes more inviting and encouraging longer or more enjoyable walking experiences. This indicates that climate comfort and greenery operate together as experiential walkability factors, shaping both physical comfort and psychological well-being.

Transport connection and destination accessibility further influenced participants' willingness to walk. Three participants mentioned problems related to buses and waiting, and one participant specifically linked quiet or dark waiting areas to feelings of unsafety. Participants also described a practical walking threshold, with three indicating that they would usually walk around 1.5 km or about a 30-minute round trip before choosing another mode of transport. These findings suggest that walkability is closely connected to the reliability of public transport, the perceived safety of waiting areas, and the proximity of everyday services such as grocery stores. In this sense, walking should be understood as part of a wider mobility system rather than as an isolated mode of travel.

Digital tools shaped how participants planned, evaluated, and motivated walking. Two participants mentioned using Google Maps to estimate walking time and reduce uncertainty, while one participant described step-tracking apps as motivation for daily walking. These comments suggest that digital tools can make walking feel more manageable by improving route predictability, time awareness, and personal motivation. However, participants also suggested that individual digital tools cannot replace broader urban improvements, such as better-timed traffic lights, clearer wayfinding, and more reliable transport information. These findings helped inform the later VR prototype by identifying safety, comfort, greenery, accessibility, and technology-supported navigation as key walkability dimensions for immersive evaluation.

4. Urban Walkability VR Prototype and Experiment

Building on the go-along interviews, a VR prototype was developed to support immersive walkability evaluation. Participants navigated the virtual environment, assessed safety and comfort, suggested design improvements, and reflected on the prototype's usability for urban planning. The aim was to examine how VR could translate walkability concerns identified in the interviews into an exploratory design-evaluation setting.

4.1. Urban Walkability VR Experiment

The VR experiment was conducted individually in a controlled environment to ensure participant safety and data quality. The VR prototype was developed using the Unity game engine and the Virtual Reality Toolkit to simulate an urban environment. The virtual environment was an immersive environment similar to a Dutch urban area, allowing for a direct comparison between real-world and virtual perceptions as all the participants are based in the Netherlands. In the VR environment, elements such as path quality, greenery, streetscape elements (trees, parks, and benches), traffic signals, and pedestrian crossings were visible and interactive.

Nine participants (n = 9), including four females and five males, with backgrounds in urban planning, urban design, or landscape architecture, participated in the study. Participants were recruited through professional networks and university mailing lists. The inclusion criteria required participants to have relevant professional or academic experience in urban planning, urban design, landscape architecture, or related fields. Professionals were selected for this phase because the aim of the VR experiment was to examine how immersive environments could support expert reflection on walkability assessment and urban design improvement. The sample was purposive and exploratory, rather than representative of all urban planning or design professionals in the Netherlands. Participants were selected because their professional expertise enabled them to evaluate the VR environment from the perspective of planning practice, design decision-making, and walkability assessment.

Participants interacted with the VR environment using a VR headset and handheld controllers that allowed navigation within the simulated urban space. During the session, participants were encouraged to verbalize their observations using a think-aloud protocol. The study consisted of three stages: a pre-interaction interview, a VR interaction session, and a post-interaction interview. Participants' point-of-view (POV) in VR was captured, along with audio data across all stages. Figure 3 shows the first-person VR perspective used during the walkability assessment. Participants provided informed consent and were allowed to stop at any time to minimize potential motion sickness. Data were anonymized, and ethical approval was obtained.



Figure 3. First-person VR perspective during walkability assessment.

Participants were given an introductory tutorial to familiarize themselves with the VR controls and environment. This step was to ensure comfort and usability, reducing any potential learning curve effects during the actual evaluation phase.

The virtual environment was a 650 × 850 m area constructed from 3D models sourced from Unity Assets, providing a realistic and immersive representation of the urban environment. The urban environment is influenced by Dutch urban design, as all participants are based in the Netherlands. The VR prototype featured interactive elements, including crosswalks, traffic signals, and areas representing varying levels of pedestrian accessibility and aesthetic value. The VR prototype was designed primarily as a visual-spatial simulation of walkability, including pedestrian-scale layout, path quality, crossings, greenery, benches, traffic signals, and selected interactive facilities. It did not simulate wind, temperature, humidity, smell, bodily fatigue, litter, graffiti, detailed maintenance conditions, or unpredictable crowd behavior. Therefore, the prototype should be understood as a tool for assessing selected spatial and visual aspects of walkability, rather than a complete simulation of embodied walking experience. Figure 4 shows the spatial layout of the immersive VR urban environment. Participants' interactions were observed and recorded, capturing their movements and verbal feedback for subsequent analysis. This approach provided rich qualitative data to understand user experiences and the potential for VR to simulate and enhance urban planning practices focusing on walkability.

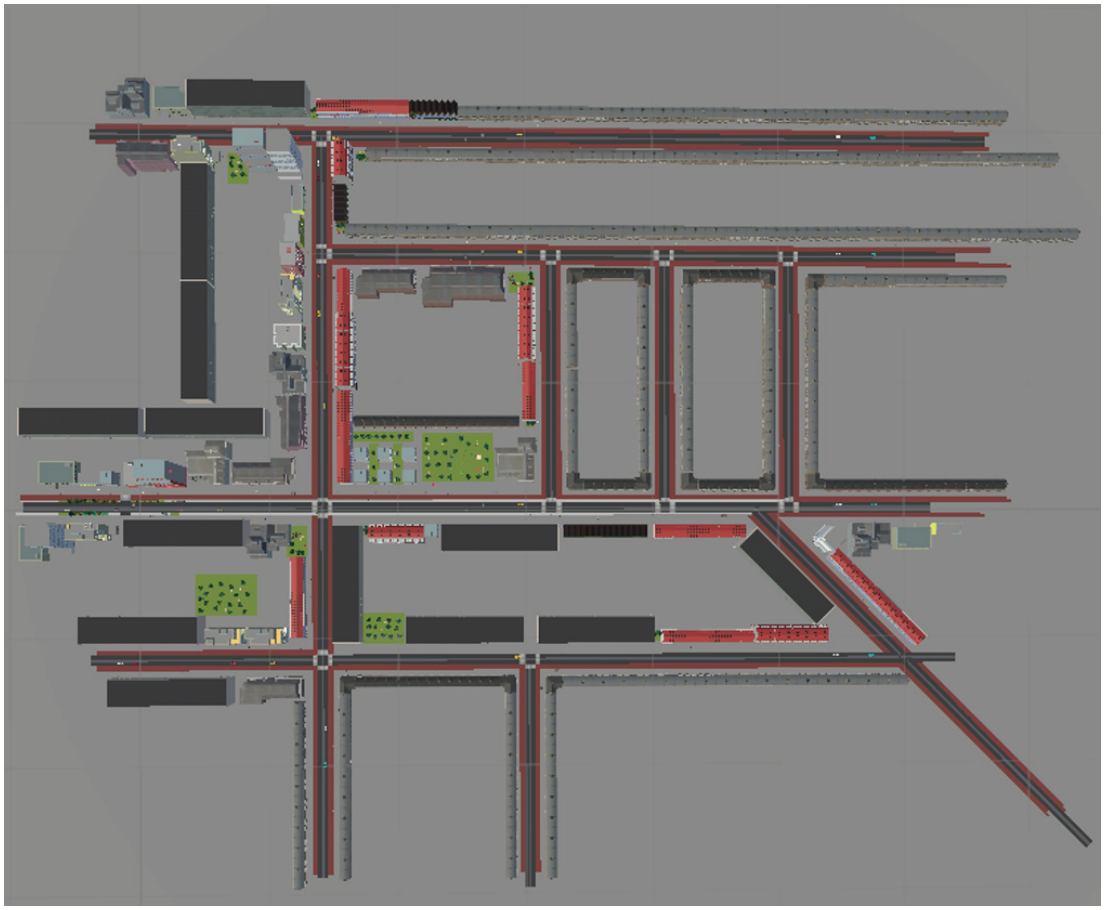


Figure 4. Spatial layout of the immersive VR urban environment.

The experiment consisted of three stages: a pre-interaction interview, a VR interaction session, and a post-interaction interview. During the VR interaction session, participants completed two tasks. First, in the navigation task, they moved through the virtual street to reach four designated checkpoints while evaluating safety and comfort. Second, in the modification task, they used their expertise to suggest changes to urban facilities at the final checkpoint to improve walkability. Participants were instructed to verbalize their observations using a think-aloud protocol during both tasks. After the VR interaction, participants reflected on their experience and discussed the potential role of immersive visualization in urban planning practice.

Table 2 maps the main resident-identified walkability issues onto the corresponding VR design variables. The purpose of this translation was not to reproduce the full complexity of the real street, but to convert selected walkability concerns into visual, spatial, and interactive elements that professionals could assess in VR. Some issues were directly represented in the prototype, while others were only partially represented or excluded because of technical and sensory limitations.

Table 2. Translation from go-along findings to VR design variables.

Go-along finding	Walkability concern	VR design variable	VR task/evaluation focus
Pedestrians felt unsafe around fast-moving bicycles and unclear bike–pedestrian boundaries	Safety; path clarity; pedestrian–cyclist conflict	Bike lanes, pedestrian crossings, and pathway separation	Navigation task: Participants assessed crossing safety and spatial separation.
Participants valued greenery, parks, and trees as calming and attractive walking features	Comfort; aesthetics; psychological restoration	Trees, green areas, parks, and public seating	Navigation task: Participants identified where greenery and seating should be improved.
Participants discussed shade, weather comfort, cold, wind, and heat exposure	Climate comfort; thermal experience	Static sunny visual condition; shaded areas through trees	Discussed during evaluation, but wind, temperature, and thermal comfort were not physically simulated.
Participants preferred daily services within a comfortable walking distance	Destination accessibility; distance tolerance	Walkable urban layout and checkpoints	Navigation task: Participants moved through the environment and reflected on distance, comfort, and route experience.

4.2. Results

To contextualize the findings, the results are presented in three stages: pre-VR interviews, VR interaction findings, and post-VR interviews. The VR think-aloud data and both interview transcripts were analyzed using the same thematic approach. The deductive coding frame focused on the two main research interests: the role of VR in supporting walkability assessment and participants' evaluation of the VR prototype. Additional codes were then developed inductively from participants' comments, including perceived immersion, scale perception, safety at crossings, need for greenery and seating, usability challenges, motion discomfort, and limitations in environmental realism. Codes were compared through consensus discussion and grouped into broader analytical themes that structured the reporting of the VR findings.

4.2.1. Interviews Before Participant VR Interaction

The pre-VR experience interviews provided in-depth insights into participants' expectations, perceptions, and perspectives on integrating VR into urban planning. Participants came from diverse backgrounds, including urban design, planning, and landscape architecture, with varying degrees of familiarity with VR technology. While some participants had basic exposure to VR, primarily through architectural visualizations and virtual walkthroughs, others had limited or no substantial experience with immersive VR applications in urban planning contexts. This variance in familiarity underscored the novelty of using immersive VR in urban planning, emphasizing the need for comprehensive tutorials and introductory experiences to bridge gaps in expertise.

Overall, the pre-VR interviews show that participants expected VR to support urban planning mainly by improving spatial understanding, communication, and accessibility of design information. As summarized in Table 3, participants had different levels of prior VR exposure, but they commonly associated VR with the ability to experience urban space from a pedestrian-scale perspective rather than only through maps, drawings, or static visualizations. Participants also expected VR to help non-expert stakeholders better understand proposed urban layouts, suggesting its potential value for public engagement and design discussion. At the same time, they anticipated practical limitations, particularly the time, cost, and technical expertise required to create realistic VR models. These pre-VR findings helped frame the subsequent experiment by showing that participants entered the VR session with both positive expectations about spatial perception and clear concerns about implementation barriers.

Table 3. Key insights and supporting quotes for interviews before VR interactions.

Key Insights	Supporting quotes
Diverse Levels of Earlier VR Exposure: Some participants had prior experience using VR for visualization, while others had never engaged with immersive VR for urban planning.	"I have seen VR used in architecture, but never interacted with it myself." (P2) "I have some experience with VR walkthroughs, but not in planning applications." (P4)
VR as a Tool for Spatial Perception: Participants recognized VR's ability to convey pedestrian-scale perspectives that traditional planning methods struggle to achieve.	"Walking through space helps me see proportions better than 2D maps." (P6) "I can feel the scale of buildings and pathways much better in VR." (P3)
Enhancing Stakeholder Participation: VR was seen as a way to engage non-experts in urban planning discussions by making complex design concepts more intuitive.	"If citizens can see the changes in VR, they will understand the plans better." (P8) "VR could help non-experts visualize how a new urban layout will function." (P5)
Challenges in Simulating Real-World Conditions: While VR offers immersive experiences, participants noted its limitations in representing real-life urban factors like weather, sounds, and human activity.	"Creating VR models takes too much time and financial resources." (P9) "We do not have the budget to develop such high-quality simulations." (P1)

4.2.2. VR Experiment

The immersive VR environment enabled participants to assess spatial layouts more dynamically, enabling them to identify areas for improvement. As one participant described, "VR gives a really good impression on how

it is to walk there and about dimensions of the footpath," and emphasized that walkability is "a movement through space."

The need for shaded areas, trees, and public seating was repeatedly raised as a way to support pedestrian comfort, especially in warm conditions. Participants also identified accessibility and wayfinding issues, including unclear separation between pedestrian areas, bike lanes, and parking spaces, and the absence of tactile paving for visually impaired pedestrians. For example, one participant pointed out, "there's no clear tactile path for blind pedestrians," adding that "the right-side lane isn't clearly separated, so blind people might not walk safely here," and proposed a fix: "I'd add a tactile paving strip for visually impaired pedestrians."

Participants also identified wayfinding as a key need for navigation and pedestrian safety. One participant suggested "clearer distinctions between pedestrian areas, bike lanes, and parking spaces" while another suggested adding arrows to the environment to support navigation. A further safety-related comment concerned crossing alignment: "the zebra crossing needs to be in line with the pedestrian crossing."

Participants noted that VR's realistic representation supported firsthand judgments about scale, spatial relationships, and experience quality. This was captured in reflections that VR enables stakeholders to "have a one-to-one ratio with your environment," and because urban designers "usually work from a plan-based view" by "looking from it above"—VR reveals experiential issues that would otherwise be missed: "Now you really experienced it like here I need greenery or functions that make this place more lively."

This capability was described as particularly valuable for evaluating user experience and identifying walkability issues that can be overlooked in non-immersive visualizations, since participants reported that in VR "you can walk multiple times," and giving "a better sense of proportions and dimensions," while also enabling assessment beyond the traditional single viewpoint because, as one participant stated, "VR allows you first of all, to focus on the things that you find important."

Comments also highlighted the importance of pedestrian-relevant signals, lighting, and traffic noise. Participants asked for traffic lights, street lighting, clearer crossing alignment, and better distinction between walking, cycling, and parking areas.

These insights suggest that VR can support iterative assessment by helping professionals identify selected spatial and experiential issues before implementation. Participants also suggested that planners should be able to modify elements directly in VR and immediately assess the effects.

4.2.3. Interviews After Participant VR Interaction

Key insights from the post-VR interviews indicate several perceived advantages of using VR as an immersive tool for urban design, particularly its capacity to offer a first-person perspective that can complement traditional 2D plans and video renderings, as one participant stated:

> Urban design is still often done in 2D. Walkability is about movement through space, and the only way to fully experience it is by walking through that space. VR allows that kind of immersive experience, which is essential for evaluating walkability.

Overall, the post-VR interviews suggest that participants perceived VR as useful for walkability assessment because it provided a first-person, pedestrian-scale perspective on urban space. As summarized in Table 4, participants valued VR for helping them understand spatial scale, crossing conditions, relationships between traffic modes, and the location of missing facilities more directly than through 2D plans or static images. They also saw potential for VR to support stakeholder communication and design discussion, particularly because different users could experience the same proposed environment and discuss possible modifications before implementation.

However, participants also emphasized that the prototype's realism remained limited. The constant weather condition, simplified pedestrian movement, limited street activity, and lack of dynamic environmental factors made the virtual environment feel less close to a real urban experience. These comments indicate that VR can support selected aspects of walkability assessment, especially spatial layout and visual perception, but should not be treated as a complete simulation of real walking. Future versions should therefore incorporate more realistic pedestrian behavior, varied weather and lighting conditions, traffic noise, street activity, and other sensory or environmental details.

Participants also identified usability and accessibility challenges. Some experienced discomfort related to joystick movement, headset weight, and prolonged use, while others noted that non-expert users may need simpler interaction methods and clearer guidance. These findings suggest that VR-supported planning workshops require careful facilitation, introductory tutorials, accessible controls, and session lengths that reduce fatigue. Therefore, VR should be understood as a complementary tool for iterative walkability assessment and stakeholder engagement, rather than as a standalone replacement for real-world observation, community consultation, or spatial analysis.

Table 4. Key insights and supporting quotes for interviews after VR interaction.

Key insights	Supporting quotes
VR Enhances Walkability Assessment: VR provides a first-person perspective that helps assess pedestrian experience, spatial interactions, and urban design flaws that may not be visible in 2D plans or static images.	"VR helps us see the scale of the city in a way we can't with maps or models." (P1) "I could walk around and immediately see where the crossings are problematic." (P4)
Potential Public Participation and Stakeholder Engagement: VR improves public engagement by making urban planning more accessible and understandable to non-experts. It can be a negotiation tool among stakeholders.	"VR makes urban planning more accessible to non-experts. It's easier for people to understand what a space will look and feel like." (P6) "By experiencing a place in VR, community members can provide more useful feedback." (P9)
VR as a Negotiation and Decision-Making Tool: VR enables real-time discussions and scenario testing, facilitating stakeholder collaboration and decision-making.	"Seeing urban designs in VR makes discussion easier because everyone can experience the same space rather than just looking at drawings." (P1) "It's a great way to test different options before construction. It allows stakeholders to visualize changes together." (P1)
VR's Limitations in Long-Term Planning: While VR is beneficial, it must be integrated with other tools and real-world validation to ensure long-term planning effectiveness.	"VR is useful for initial design evaluations, but it should be combined with real-world data to be more reliable." (P5) "We can't rely only on VR. It's a tool, but urban planning requires more data from real-life environments." (P8)

5. Discussion

5.1. Mixed-Method Approach

This study's mixed-method approach revealed that pedestrian walkability depends on more than sidewalks. Residents valued safety, comfort, connectivity, and aesthetics, while professionals in VR identified similar concerns, including unclear crossings, missing tactile paving, insufficient seating and shading, and the need for better lighting and signage. These findings support the view that walkability is a multidimensional and subjective experience.

The immersive VR session suggested the value of citizen-centric digital tools for professional reflection. The virtual walk helped experts identify micro-scale issues that may be difficult to capture through standard maps alone, while also supporting discussion of possible design changes. This aligns with studies showing that VR can support participatory public-space design (Dane et al., 2024; Evers et al., 2023).

In practice, VR can be used in early-stage design workshops to complement GIS indices, walking audits, and community feedback. However, it should be combined with real-world data and careful facilitation to avoid over-reliance on an incomplete simulation.

5.2. Scalability and Replicability

The VR prototype was developed and tested using a consumer-grade VR headset and a computer with moderate specifications, suggesting that VR-supported walkability assessment may be accessible to planning researchers, municipalities, and design teams. Remaining barriers include model development time, technical expertise, headset availability, facilitator training, and public accessibility. WebXR platforms, hybrid VR/screen-based sessions, and reusable urban asset libraries could improve scalability.

5.3. Limitations and Future Work

This research used a small, exploratory sample of 14 local residents for the go-along interviews and nine professionals for the VR experiment. These participants were selected to provide situated pedestrian insights and professional design reflections, rather than to represent the full diversity of Eindhoven residents or urban planning professionals. Therefore, the findings should be interpreted as exploratory evidence of how go-along interviews and VR can be combined for walkability assessment, rather than as generalizable conclusions about walkability experience or planning practice more broadly. Future research should include larger and more diverse participant groups, including residents of different ages, genders, mobility abilities, cultural backgrounds, and levels of familiarity with the study area. Future studies should also involve a broader range of planning stakeholders, including municipal officers, transport planners, community representatives, and non-expert residents, to examine how VR-supported walkability assessment may function in more inclusive participatory planning settings. The VR prototype, while detailed, lacked some realism (e.g., static weather, stiff avatars), which participants noted and should be improved in future research. Some participants experienced minor motion discomfort, which is a potential side effect of using the VR headset.

6. Conclusion

This research investigated how immersive VR can support walkability assessment and urban design evaluation by bridging the gap between objective planning metrics and subjective pedestrian experience.

The findings support the view that walkability is determined not only by physical infrastructure but also by subjective perceptions such as safety, comfort, accessibility, and aesthetic quality. Through go-along interviews, this research captured how pedestrians experience urban environments in real time, revealing micro-scale issues such as conflicts with cyclists, lack of greenery, and discomfort related to weather and public transport conditions. These insights highlight the limitations of traditional approaches, which often fail to represent the subjective experience of walking.

The immersive VR experiment extended these findings by providing an environment in which urban planning professionals could assess and modify urban space. The structured protocol, combining navigation tasks, real-time think-aloud feedback, and pre- and post-interviews, enabled participants to identify walkability issues that may be less visible in static representations, including perceived vulnerability at crossings, lack of shading, and unclear spatial boundaries. Importantly, the ability to interact with the environment and propose design changes in situ supports a more iterative and reflective design process. The integration of qualitative data across all stages further suggests that VR can function not only as a visualization tool, but also as part of an exploratory method for capturing and analyzing perceived walkability.

At the same time, the findings indicate that VR should be understood as a complementary tool rather than a standalone solution. Limitations in realism, physical comfort, and the simulation of dynamic urban conditions highlight the need for further development and integration with real-world data sources. Future work should focus on enhancing environmental realism, expanding participant diversity, and incorporating dynamic factors such as weather, traffic, and social activity to strengthen the validity of VR-based assessments.

In conclusion, this exploratory study suggests that immersive VR can complement go-along interviews and conventional spatial analysis by supporting professional reflection on walkability issues before implementation. By offering an immersive pedestrian-scale perspective during the design process, VR may help bridge real-world pedestrian experience and early-stage design evaluation, while remaining dependent on further validation, broader participant inclusion, and integration with real-world data.

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Conflict of Interests

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