Comparing Reality and Cinematic Virtual Reality for Visual Walkability Evaluation: An Exploratory Study

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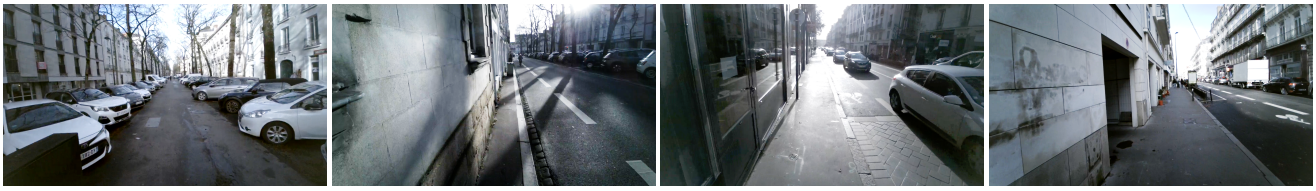
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(a) Path 1 (b) Path 2 (c) Path 3 (d) Path 4

Figure 1: Snapshots of 4 paths used in the experiment, extracted from the 360° videos used in the CVR condition: The first and fourth paths had comparable sidewalk width and traffic presence, while differing in vegetation and stationary vehicles. The second and third paths had similarly narrow sidewalks, with the second path including more vegetation than the third.

Abstract

This exploratory study examines how the evaluation context may influence the experience of assessing visual walkability in Cinematic Virtual Reality (CVR) and in the real world. While previous research has demonstrated the potential of CVR for visual walkability evaluation, its accessible and repeatable 360° representations also come with limited interactivity, which may shape how users experience visual walkability evaluation across its core dimensions – *Accessibility*, *Safety*, *Comfort*, and *Pleasurability*. This was a point of departure for our user study. Five participants evaluated four urban streets through both in-person walks and 360° CVR experiences, using eye-tracking, questionnaires, and interviews. Semantic segmentation of participants' viewports revealed distinct visual content patterns: CVR emphasized facades, greenery, and sky, while on-site viewports included more sidewalks and road surfaces. Participants identified similar urban features in both conditions but experienced them differently. CVR demonstrated particular strengths in assessing higher-level visual qualities of walkability, such as *comfort* and *pleasurability*, while its use for assessing more embodied dimensions, such as *safety* and *accessibility*, remained more limited compared with on-site evaluation.

CCS Concepts

• **Human-centered computing** → *Field studies*; *Virtual reality*; **Empirical studies in HCI**.

Keywords

Cinematic Virtual Reality; Visual Walkability Evaluation; User Experience; Urban Experience; Field Study

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1 Introduction

Walking contributes to both physical and mental well-being [10], and the quality of the walking experience largely depends on how

pedestrians perceive their surroundings [6]. In this study, we explore the evaluation of visual walkability, i.e., the environmental qualities that affect how an individual visually perceives an area as suitable for walking [15, 18]. Walkability audits are widely used by researchers and urban practitioners to evaluate pedestrian environments, support urban planning decisions, and assess street improvements. Although on-site audits remain a common reference approach, they are resource-intensive and difficult to reproduce under comparable conditions [15].

To address these practical limitations, we turned to cinematic virtual reality (CVR), which uses immersive 360° video playback and enables continuous first-person visual exploration without interactive navigation. Compared with fully interactive VR environments, 360° video-based CVR is easier to capture in real urban settings and offers a repeatable high-fidelity representation of existing streets, but it also limits interaction, locomotion, and embodied control [7]. Although previous research has provided evidence supporting the potential of CVR to quantify visual walkability [7, 11, 14], less is known about how this trade-off between accessible, repeatable capture and limited interactivity shapes users' experience of evaluating walkability. In particular, on-site and CVR-based evaluations involve different levels of perceptual engagement, bodily involvement, and environmental cues, which may affect how participants assess visual walkability.

To bridge this gap from a user-centered perspective, we conducted a comparative exploratory study ($N = 5$) that combined on-site visual walkability evaluations on four streets with an eye-tracking device, with corresponding CVR-based evaluations of 360° recordings along the same streets in a mid-size city in Western Europe. We employed both semantic segmentation of participants' viewports as well as semi-structured interviews, as this approach enabled not only direct comparison of how users experienced urban environments when evaluating walkability on-site and through CVR, but also allowed us to collect their reflections on the realism, limitations, and potential role of CVR as an evaluation medium.

This paper contributes an exploratory comparison of on-site and CVR-based visual walkability evaluation. We demonstrate how the evaluation context may shape participants' experience, the visual cues they attend to, and the perceived relevance of CVR as a complementary assessment medium. We present participants' qualitative accounts regarding the key walkability dimensions identified in prior research [1], i.e., *Accessibility, Safety, Comfort, and Pleasurability*.

2 Related work

In recent HCI research, CVR has been used as an evaluation medium to investigate how users perceive real-world environments through immersive 360° videos [2, 16]. Compared with fully interactive virtual reality, CVR offers an accessible and reproducible way to capture real-world urban scenes, but it nevertheless limits interaction, as immersion takes place within a pre-recorded footage. Several studies have examined the validity of CVR and VR in evaluating walkability by comparing immersive experiences with on-site assessments [7, 8, 11]. Kim and Lee [7] concluded that CVR offers some advantages over *online* audits based on Street View imagery, as omnidirectional video provides a more continuous and immersive representation of streetscapes. More specifically, they showed that omnidirectional video-based CVR produced walkability assessments closer to *on-site* audits, especially when it comes to enclosure, safety, and overall atmosphere. However, aspects requiring fine visual detail or non-visual sensory information, such as pavement quality or microclimate, remain better assessed through on-site experience. Vo and Kim [14] conducted a study using 360° immersive video to compare perceived walkability in commercial streets. Their study highlighted that while CVR captures visual and spatial features such as sidewalk width, facades, and vibrancy, participants reported decreased awareness of accessibility barriers compared to their real-world walking experience. Despite these studies suggesting that CVR is a useful tool for visual and spatial assessment, it remains unknown how the medium itself influences the experience of assessing pedestrian visual walkability. In other words, most prior research focuses on the similarity of assessment results between CVR/VR and on-site evaluations, rather than on how users perceive, interpret, and compare environments depending on the assessment context. That marks a salient motivation for our research.

In relation to that, eye-tracking technology, and resulting eye movement analyses have increasingly been used in field studies to uncover how pedestrians visually engage with urban environments during real-world navigation, helping identify which urban elements attract attention during walking. Sultana et al. [13] used wearable eye-trackers to collect gaze data across elements of the streetscape (e.g., sidewalks, crosswalks, greenery, and building facades) and demonstrated that features linked to spatial clarity and safety (e.g., curbs, well-defined pedestrian paths) received prolonged attention, while vegetation played a key role in visual comfort and environmental appeal. Zhao et al. [17] applied eye-tracking to observe pedestrian behavior in complex real-world scenarios. They recorded pedestrian gaze behavior in situations requiring increased vigilance, such as before road crossings, and found that visual attention patterns varied with context. In their study, pedestrians tended to focus more on the footpath (typically $40 - 50\%$ of their fixation time) and adjusted their gaze depending on whether streets were pedestrianized or vehicle-accessible. Collectively, these studies show that visual engagement during walking is situated and task-dependent. However, they primarily focus on real-world navigation, rather than comparing how people visually engage with the same environment on-site and through CVR. In turn, our study examines exactly this comparison.

In sum, our exploratory study draws upon these related works and extends them by specifically investigating how pedestrians perceive urban walkability when immersed in 360° video-based CVR, based on a set of established walkability dimensions from Alfonzo [1] i.e., *Accessibility, Safety, Comfort, and Pleasurability*.

3 Study Design and Method

3.1 Study rationale and research question

This exploratory study compares on-site and CVR-based visual walkability evaluation without aiming to establish equivalence between the two conditions. The research question guiding this work is: *"How does the context of evaluation (on-site vs CVR) influence participants' experience of evaluating visual walkability?"*



Figure 2: Hierarchy of walking needs (reproduced from [1]).

3.2 Study setting and evaluation conditions

Participants evaluated the walkability of four urban walking paths under two conditions: an on-site walking condition (i.e., real world), and a CVR condition using panoramic video recordings of the same streets with sound recorded under nearly identical climatic and temporal conditions. This design supported spatial and visual comparison across evaluation contexts, while acknowledging that the on-site condition remained naturally variable in terms of traffic, pedestrians, ambient sound, and other contextual cues. The four selected field paths represent typical urban walking environments, varying in sidewalk width, vegetation, traffic presence, and stationary vehicles (Figure 1).

3.3 Questionnaire

We designed a visual walkability questionnaire based on the walking needs hierarchy from [1] (Figure 2), which emphasizes that pleasurable walking experiences can only be achieved once basic needs such as feasibility, accessibility, safety, and comfort are met. Since all our selected paths were feasibly walkable, we excluded the *Feasibility* dimension from the questionnaire. We employed a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to rate accessibility, safety, comfort, pleasurability, and willingness to use the path for daily commute, which served as a proxy for overall walkability. The questionnaire items were: "This path is accessible," "This path is safe," "This path is comfortable," "This path is pleasurable," and "I would use this path for daily commute."

3.4 Procedure

All participants completed the on-site condition first, followed by the CVR condition. This fixed order was chosen to allow participants to compare the CVR experience with a recently experienced real-world walk. However, this design may also have influenced the CVR evaluation through familiarity with the paths and memory of the on-site experience.

For the on-site experiment, participants wore eye-tracking glasses (Tobii Pro Glasses 3) that also recorded the on-site environment as viewed by participants. The integrated gaze tracking enabled us to identify the elements participants looked at within their visual field during the walk. Immediately afterward, participants completed the previously described questionnaire containing the five questions related to the chosen walkability dimensions.

Next, we performed the CVR condition in the laboratory, using an HMD (Meta Quest Pro) with built-in eye-tracking to display a first-person 360° video with sound recorded with an Insta360 Pro 2 camera of the same four streets. We implemented an arm-swinging method from the prior art [4, 9] to allow participants to advance the video feed during the experiment. This interaction was intended to create a minimal sense of active progression, but it did not reproduce real locomotion or the full attentional demands of walking. We therefore treat it as part of the CVR evaluation setup rather than as an equivalent to on-site walking. The CVR condition experiment was followed by the same questionnaire as the on-site experiment to allow comparison and a short semi-structured interview to elicit participants' reflections and reactions.

3.5 Participants

As our goal was to examine the feasibility of the two methods involved and collect preliminary observations, we invited five participants to take part in this study: three women and two men aged 32 to 63 years ($M = 50.6$, $SD = 13.6$). We adopted purposive sampling and recruited participants from our professional networks. All of them have completed at least an undergraduate degree; three held doctoral degrees in various disciplines; none had a background in walkability studies. All participants had lived in the city where the experiment took place for several years, allowing for some familiarity with the study area; however, they were unaware of the specific purpose of the experiment. Only one participant reported being familiar with VR, while the others had little or no prior exposure and no regular use. This limited prior exposure to VR is important to consider when interpreting participants' comfort, sense of realism, and viewing behavior in the CVR condition. Despite our small sample size, the study revealed informative insights into how participants experienced and compared the two evaluation contexts.

3.6 Data collection and Analysis

Our data collection included both quantitative and qualitative approaches. For each participant and each path, we recorded eye-tracking data and viewport information (the user's effective field of vision) for both conditions, on-site and in CVR. In the on-site condition, the viewport corresponded to the scene video captured by the eye-tracking glasses. In the CVR condition, it corresponded to the participant's field of view within the 360° video displayed in the headset. We applied semantic segmentation to sampled viewport frames extracted from the recordings at 60 fps. That allowed us to estimate the proportion of different visual categories present in participants' viewed environment across conditions.

In addition to quantitative evaluation, we administered a questionnaire and conducted follow-up interviews. We opted for semi-structured interviews to explore participants' experiences and perceptions of visual walkability in both CVR and real-world settings. The conversation began with general questions to establish a relationship and provide context about the participant's background. The discussion then shifted to the CVR experience. We asked participants to describe their feelings while walking in the simulated environment, including whether the experience felt natural or unnatural, comfortable or uncomfortable, and invited them to elaborate on the reasons for these perceptions. We then prompted our participants to compare the CVR walk with their previous real-world walk with the view of identifying which aspects were effectively replicated in VR and which were missing or could be improved. We specifically asked which aspects of walkability were most important to each participant in each environment and why, as well as the perceived

advantages and disadvantages of using CVR for visual walkability evaluation.

To unpack our research question, we further asked participants about the environmental objects and visual cues involved in their evaluation process. They described the visual stimuli they focused on when rating walkability and explained why these cues were important. We explored whether different objects or environmental elements captured their attention during the on-site walk compared to the CVR simulation. Each interview concluded with an open-ended invitation for participants to share any additional thoughts on their two experiences.

We transcribed the interviews verbatim and conducted affinity analysis [5]. We held several data alignment sessions to create and maintain the affinity wall, clustering data points (from our interviews) with close semantic meanings. This process enabled the identification of recurring themes related to perceived realism, visual attention, walkability dimensions, and differences between on-site and CVR evaluation.

4 Comparative Findings

Below, we organize the findings around three complementary perspectives: (1) the visual content present in participants' viewports, (2) the objects they reported as salient during evaluation, and (3) the walkability dimensions they discussed across on-site and CVR conditions.

4.1 Visual content across conditions

To provide an initial descriptive comparison of the visual content present in participants' viewports between CVR and on-site conditions, we applied semantic segmentation to the viewport data with the Mask2Former model [3] trained with Mapillary Vista dataset [12]. Our analysis summarizes the pixel ratio of various environmental categories within the participants' field of view. We selected categories focusing on major streetscape elements related to walkability, including buildings, vegetation, roads, sidewalks, cars, and sky. Elements not included in these categories were grouped into an "Other" class. The objective was to characterize which types of urban elements occupied participants' viewed environment across conditions.

We focused on six streetscape categories commonly associated with walkability in prior work: Building, Sidewalk, Sky, Vegetation, Car, and Road. Table 1 presents the average values across all participants and all paths for both CVR and on-site experiments. The analysis included 40 recordings in total (5 participants × 4 streets × 2 conditions).

The results indicate notable differences in the visual content present in participants' viewports between environments. In CVR, buildings occupied a larger proportion of participants' viewports (43.13% vs. 31.70%) and the sky was also more visible (7.19% vs. 2.01%) compared to the on-site condition. This suggests that CVR made large-scale visual features more prominent in the viewed scene, possibly due to the immersive yet constrained field of view provided by the headset. In contrast, during the on-site experiment, roads and sidewalks occupied a larger proportion of the viewed environment (21.64% and 18.42%), which occupy a substantial part of the visual field during physical walking, whereas they appear less dominant in the CVR condition (10.16% and 7.34%, respectively). Vegetation was also more represented in CVR viewports (14.98%) than on-site ones (6.52%), suggesting increased visual salience of greenery in the absence of non-visual sensory cues. Cars appeared at similar levels in participants' viewports accross both conditions (CVR 10.05%, on-site 9.50%), indicating that certain dynamic or potentially obstructive elements remain visually salient regardless of evaluation context.

In summary, the semantic segmentation results show that CVR emphasizes visually prominent background elements, such as buildings, vegetation, and the sky, while on-site viewports included more to ground-level elements, including roads and sidewalks. These differences describe how the visual content available to participants varied across evaluation contexts and provide a basis for our affinity analysis.

4.2 Objects attracting attention across conditions

To address participants' experience of evaluating visual walkability, we asked participants to reflect on which elements of the streets they noticed and considered relevant in both CVR and on-site conditions. Throughout the interviews, they described a set of recurring objects and features that shaped their evaluation of walkability regardless of the medium. These included moving and parked vehicles, other pedestrians, shops and facades, as well as obstacles such as poles, bins, or stairs. Greenery and trees were also mentioned as salient visual cues in both settings. These accounts indicate that similar categories of objects were reported as relevant across conditions, although their perceived importance and experiential role differed.

Traffic and pedestrians emerged as salient elements in both conditions. Participants consistently noticed moving and parked vehicles as well as the presence of other pedestrians when evaluating walkability. Participant 2 emphasized: *"Traffic is really important to me when I walk. Moving traffic, but parked cars too."* Several participants noted that on-site, vehicles and pedestrians generated immediate vigilance and influenced feelings of safety, whereas in CVR they were still noticed but felt less urgent, as they carried no physical risk. Participant 3 observed: *"on-site, I look at a little bit of everything, [including] people [...] I tend to look at people more naturally. In virtual reality, I notice them, but they have to come to me [so that I can see them]."*

Shops and facades were also frequently reported as relevant elements. Participants associated commercial activity and animated facades with street vitality and practical interest. Participant 1 explained: *"I personally prefer to walk on the kind of road where there are more shops on both sides [...] it has some vitality."* Some participants reported that in CVR, they were compelled to observe facades and shopfronts, while on-site these elements could be overlooked when attention was directed toward traffic or obstacles.

Street furniture and obstacles, such as poles, bins, and steps, were described as part of the walking experience in both conditions. Participant 5 highlighted on-site constraints: *"The sidewalk is already not wide, but in addition, there is a step at the entrance to the building that eats half of it."* While obstacles influenced attention

Table 1: Average pixel ratio of semantic segmentation classes in the participant viewport in CVR and in on-site experiments to illustrate differences in visual content distribution across conditions.

Condition	Building	Vegetation	Road	Sidewalk	Car	Sky	Other
CVR	43.13%	14.98%	10.16%	7.34%	10.05%	7.19%	7.15%
On-site	31.70%	6.52%	21.64%	18.42%	9.50%	2.01%	10.21%

in both conditions, participants reported that they sometimes appeared exaggerated in CVR (such as poles), whereas in real life their impact was more physical, requiring detours or creating danger. Natural elements, including trees and greenery, were consistently noticed across both conditions. Participants associated greenery with comfort and visual pleasantness, though they noted its experiential impact was more tangible on-site due to factors such as shade, seasonal variation, and atmosphere. Participant 4 stated: *"When there is a little greenery [...] it helps to brighten up the path and make it much more pleasant."*

In sum, participants reported focusing on similar categories of objects when evaluating walkability in CVR and on-site, but noted differences in how these elements were experienced. While CVR supported attention to large-scale and visually dominant features, on-site walking highlighted dynamic, safety-related, and physically constraining elements. These observations complement the quantitative analysis of visual content and help explain how the evaluation context influences participants' experience of assessing visual walkability. They also suggest that CVR provides certain visual and spatial cues in a repeatable way, while reducing the perceived urgency of dynamic, small-scale, and socially situated aspects of urban walking, such as traffic risk, spontaneous pedestrian interactions, or uneven pavement.

4.3 Visual Walkability dimensions across conditions

During the experiment, participants were also asked to evaluate the different dimensions of walkability – *Accessibility, Safety, Comfort, Pleasurability, and Willingness to use the path for daily commute* – in both CVR and on-site conditions. Rather than focusing on numerical differences, this section reports how participants described similarities and differences in their evaluation experiences across conditions. The questionnaire scores are therefore presented as descriptive indicators intended to support the qualitative analysis rather than as statistically generalizable comparisons. Table 2 presents descriptive average scores across conditions. The descriptive trends we observed across dimensions appeared broadly comparable between CVR and on-site evaluation, although differences emerged on specific path/dimension combinations. While the questionnaire was not designed to establish equivalence between CVR and on-site ratings, the descriptive scores suggest that both conditions identified Path 2 as the lowest-ranked path across all walkability dimensions. This indicates that CVR may capture strong contrasts in visual walkability, particularly in clearly constrained environments. However, the relative ranking of the other paths varied across conditions, especially for comfort, pleasurability, and willingness to use the path for daily commuting, suggesting that CVR and on-site evaluation should not be treated as directly interchangeable for comparing paths.

Accessibility was perceived as partially assessable in CVR, especially for understanding street layout, crossings, and overall width. However, participants consistently noted that obstructions visible in CVR did not impose the same constraints as in reality and were only fully recognized on-site, where physical presence required movement adjustments and obstacle avoidance. Participants thus described CVR as suitable for assessing structural accessibility but insufficient for evaluating fine-grained, tactile, or physically constraining elements.

Safety, understood here as safety related to traffic rather than crime, showed the strongest divergence between conditions. Participants reported a reduced sense of risk in CVR, which lowered vigilance and altered safety judgments. While some safety-related reflexes persisted, the absence of real danger and reduced auditory salience in CVR diminished the perceived urgency of traffic-related threats. By contrast, on-site walking heightened situational awareness and caution, leading to stricter safety assessments grounded in embodied exposure to traffic and surrounding activity.

Comfort was generally perceived as more comparable across conditions, as participants relied on visual indicators such as openness, continuity, and crowding. However, CVR lacked embodied and sensory cues, such as the feeling of the pavement, which influenced comfort more strongly in reality. As a result, comfort in CVR was described as simplified and less nuanced, even when overall impressions seemed similar.

Participants described *Pleasurability* as highly similar and identifiable in both CVR and on-site evaluations. They relied on visual composition, facades, greenery, and sky visibility as common reference points. CVR sometimes enhanced visual appreciation by allowing participants to focus on architectural details without safety concerns, while on-site walking enriched pleasantness through sound, air, and seasonal atmosphere. Participants thus described pleasurability as visually accessible in CVR but experientially richer in reality. Taken together, the participants' reflections suggest that CVR can reproduce several aspects of walkability evaluation with reasonable fidelity, while others remain more closely tied to on-site experience.

Accessibility and *safety* were both recognizable in CVR, but their assessment was consistently shaped more strongly by on-site embodied awareness and sensory stimulation. *Comfort* also showed a certain similarity across conditions, as participants identified similar visual and spatial indicators of ease, with only minor differences related to noise or weather. *Pleasurability* was evident in both settings; however, CVR tended to highlight architectural and visual composition, whereas on-site walking introduced atmospheric and sensory qualities that influenced perception in ways the headset could not replicate. This suggests that CVR can serve as a valuable complementary method, but not a complete replacement for on-site walkability studies. It can be deemed particularly beneficial in

Dimension	Path 1	Path 2	Path 3	Path 4
Accessibility	4.02 / **4.10**	**2.38** / 1.90	2.60 / **3.50**	3.58 / **3.80**
Safety	**4.36** / 4.30	**2.30** / 1.70	2.78 / **3.60**	3.38 / **3.70**
Comfort	**3.88** / 3.50	**1.90** / 1.80	2.72 / **3.50**	3.58 / **3.70**
Pleasurability	**3.32** / 2.60	**1.86** / 1.60	**3.04** / 3.10	**3.36** / 3.00
Willingness to Use for Daily Commute	**3.98** / 3.60	**2.04** / 1.80	3.48 / **3.80**	3.68 / **3.70**

Table 2: Average scores of visual walkability dimension evaluations on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) across conditions (presented as CVR / On-site)

the walkability evaluation studies that focus on examining specific visual details of the environment or assessing related aspects of pleasurablity and comfort.

5 Discussion

5.1 Implications for CVR-based visual walkability evaluation

The findings of this exploratory study provide new insight into how the evaluation context (CVR or on-site) influences the experience of assessing visual walkability. The semantic segmentation and interview findings indicate that the evaluation context influences not only the visual information participants are exposed to, but also how they interpret this information when assessing walkability. Although participants consistently reported attending to similar categories of urban elements across conditions, the evaluation context influenced the relative importance they attributed to these elements. In particular, visually dominant environmental features, such as façades, greenery, and the overall spatial composition of streets, remained readily assessable in CVR, whereas dimensions relying more strongly on embodied interaction with the environment, such as *accessibility* and *safety*, were more closely tied to the on-site experience.

Collectively, these findings directly address our research question by showing that the evaluation context influences participants' experience beyond differences in visual content alone. These findings extend previous works [7, 11] investigating the use of CVR for visual walkability assessment by highlighting the influence of the evaluation context on participants' experience. Rather than focusing solely on the similarity between CVR and on-site evaluations identified in the prior art [7], our results suggest that understanding how the evaluation context shapes participants' experience provides additional insight into interpreting visual walkability assessments. From this perspective, CVR appears particularly well suited for applications requiring controlled, repeatable, or remote evaluations, while remaining complementary to on-site assessment.

5.2 Limitations and future work

This study has several limitations that should be considered when interpreting the findings. First, the exploratory study involved a small number of participants evaluating four urban paths. The questionnaire scores should be interpreted as descriptive observations rather than evidence of equivalence between CVR and on-site evaluation. Second, because all participants experienced the on-site condition before the CVR condition, carryover and familiarity effects cannot be excluded. This ordering was intentionally chosen to facilitate direct comparison during the interviews, but future studies should counterbalance the order of conditions. Ultimately, while our selected paths covered contrasting urban situations, they represent only a limited range of walking environments. Future work should therefore consider larger and more diverse participant groups, a wider variety of urban contexts, and different types of immersive environments to further investigate how specifically different constituting elements of the evaluation context play in visual walkability assessment.

6 Conclusion

This exploratory study examined how the evaluation context influences the experience of assessing visual walkability in on-site and Cinematic Virtual Reality (CVR) conditions. Our findings suggest that CVR should be considered as a complementary evaluation context rather than a direct substitute for on-site assessment. Its current ability to measure low-level perceptions of walkability, such as *safety* and *accessibility*, with the same accuracy as on-site observation remains uncertain. Nevertheless, CVR appears particularly well suited to assessing higher-level visual qualities of walkability, such as *comfort* and *pleasurability*, offering valuable opportunities for controlled, safe, accessible, and reproducible evaluations.

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