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ORIGINAL ARTICLE

The influence of urban configuration on wayfinding propensity: A video game-based study

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Abstract

This study investigates how urban configuration, the spatial arrangement, and characteristics of the built environment, particularly the contrast between high-rise and low-rise settings, influence wayfinding propensity. Building on Credé and Fabrikant [Let's put the skyscrapers on the display—decoupling spatial learning from working memory. In: Freksa C, Winter S (eds) Proceedings of workshops and posters at the 13th international conference on spatial information theory (COSIT 2017). Springer, Cham, pp 163–170, 2018] assertion that global landmarks improve wayfinding by reducing cognitive load, this research explores how landmarks interact with urban configurations to affect individuals' wayfinding. Using three virtual environment configurations in the video game Grand Theft Auto V, the study evaluates the wayfinding performance of 50 participants. The results highlight four significant findings: first, high-rise environments significantly increase the perception and importance of city image elements and urban design qualities for wayfinding; second, analysis of variance revealed statistically significant differences in wayfinding times between high-rise and low-rise environments, showing the critical role of urban configuration in shaping navigation efficiency; third, multiple regression analysis demonstrated that improvements in individuals' wayfinding time and route knowledge are more pronounced in high-rise settings; and lastly, route-following behavior varies notably across configurations, highlighting differences in the perception of city image elements. Collectively, the findings of this study offer valuable insights into the influence of urban configuration, image elements, and urban design qualities on wayfinding, contributing to the development of more intuitive urban areas that enhance navigational efficiency and user experience.

Keywords Urban configuration · Wayfinding · Image elements · Virtual reality · *Grand Theft Auto*

Introduction

Wayfinding, an essential daily activity that occurs in both indoor and outdoor environments (Dong et al. 2022), is necessary for understanding how individuals navigate and experience cities. It involves a person's ability to move from an origin point to an unseen destination by navigating paths and routes, relying significantly on cognitive and behavioral skills (Allen 1999). During wayfinding, individuals derive spatial knowledge from their surroundings (Ishikawa and Montello 2006), developing cognitive maps that support navigation (Wiener et al. 2009). These cognitive maps are reinforced by visual cues and indicators that help people form navigable mental representations, even when specific details of a city escape their memory. Recent research highlights the central role of landmarks in facilitating wayfinding, differentiating between global and local landmarks. Global landmarks, observable from several positions in an

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environment, provide a coherent reference frame that aids in the formation of cognitive maps and reduces cognitive loads (Credé and Fabrikant 2018; Credé et al. 2020). This is especially apparent in high-rise urban environments characterized by high wayfinding complexity. Conversely, local landmarks, which can only be observed in a sequential manner, require increased cognitive resources for assimilation into a cognitive map, thereby increasing the difficulty in wayfinding (Credé et al. 2020).

Lynch (1960) identified several fundamental similarities across cities, which he termed the "elements" of urban environments: paths, edges, nodes, districts, and landmarks. These elements function as the foundational components for constructing or analyzing a city's image. However, the specific contribution of these elements to wayfinding remains a complex issue for urban designers, as their significance likely varies across different contexts. A profound understanding of human wayfinding behavior in diverse urban configurations can amplify our knowledge of cognitive processes and spatial knowledge acquisition (Fig. 1).

Empirical studies have suggested that environmental configuration significantly influences wayfinding decision-making (Conroy 2001). O'Neill (1991), in his model of architectural legibility, emphasizes the role of topological and spatial configuration in facilitating navigation. This is because understanding the spatial characteristics of an environment is essential for how individuals navigate and orient themselves. In this context, topological and spatial configurations pertain to the arrangement of nodes, pathways, and the spatial relationships between different environmental elements, rather than solely focusing on the physical characteristics such as building density or height. An example of spatial configurations within the context of O'Neill's work includes the arrangement of spaces within a shopping mall, where pathways, landmark stores, and open spaces play an important role in guiding visitors' movements. These configurations, often designed with considerations of both functionality and aesthetics, significantly affect how individuals perceive and navigate space. According to O'Neill, legibility refers to the ease with which an environment can be understood and navigated, which is influenced by factors such as its spatial layout. He introduces metrics such as Inter-connection Density (ICD) to gauge configuration complexity and also serve as a predictor of wayfinding performance. His research identified two types of configurations that influence legibility: topological and spatial. Topological configuration refers to the connections between choice points in an environment, while spatial configuration pertains to the physical layout of the environment. Despite its insights on topological complexity in enclosed built environments, the model's applicability to the city-scale environment is limited due to its heavy reliance on ICD and oversight of the higher level of variability in urban cognitive mapping. One notable area for improvement in O'Neill's research could be the integration of more diverse environmental contexts and user experiences. His initial studies were largely conducted in relatively controlled settings. Expanding the scope to include more variable, complex urban settings could offer deeper insights into the influence of different spatial configurations on wayfinding.

This study examines specific urban settings that are shaped by factors such as building heights, landmark presence, and urban development patterns, which define areas



Fig. 1 Virtual environments used for the wayfinding experiment: Vinewood, a low-rise environment; Little Seoul, a mid-rise environment; and Pillbox Hill, a high-rise environment

with similar characteristics. The failure to scrutinize the interaction between these factors across different outdoor environments may introduce uncertainties and limit the generalizability of wayfinding research to more complex urban scenarios. This oversight may result in a limited understanding, potentially overlooking key details critical for enhancing wayfinding effectiveness in complex urban areas. Prior research has mainly concentrated on comparing wayfinding performance across specific user groups such as adults and children (Jansen-Osmann and Fuchs 2006), different genders (Schmitz 1999), building types (Mandel 2018), geometry (Frankenstein et al. 2010), individual behavioral patterns, and environmental–spatial factors (Downs 2001; Schneider and Taylor 1999). However, these studies have not fully explored the interrelationships between urban environment elements, configuration types, and wayfinding behavior, pointing to gaps that require further investigation. These research gaps have left several aspects of how outdoor urban areas influence daily travel and wayfinding unexplored, despite recognition of urban density's role in enhancing environmental legibility (Brunyé et al. 2010; Hölscher et al. 2011; Emo 2012; Chrastil and Warren 2014; Li and Klippel 2016). In line with Kubat et al. (2012), our research underscores the need to focus on the overall structure of the environment and transitions across it, rather than focusing solely on its local features. A narrow focus on local features like signage and key facilities, overlooking how people interact with and understand the configuration, may not sufficiently support wayfinding. Configurational parameters and urban design elements, such as building height profiles and signage, significantly impact movement patterns in complex urban settings.

In this study, urban configuration refers to the spatial arrangement and characteristics of the built environment, with particular emphasis on the contrast between high-rise and low-rise urban settings. This concept encompasses the vertical and horizontal organization of buildings, streets, and other urban elements that collectively shape the urban landscape. The primary aim of this study is to investigate the relationship between urban configurations and wayfinding performance, exploring how variations in urban configuration influence perception, the importance of city image elements, urban design qualities, and overall wayfinding performance. The study advances Credé's (2018) research by investigating how different urban configurations, particularly high-rise versus low-rise environments, influence wayfinding performance. Using a video game-based virtual environment, we assess the impact of different urban settings on individuals' wayfinding abilities, perceptions of design qualities, and interactions with environmental cues. The goal is to offer insights for creating more intuitive urban designs that enhance wayfinding performance and user experience. In the context of existing research, this study aims to add clarity to the role of urban configurations in environmental legibility. We strive for a holistic understanding of urban wayfinding by investigating a spectrum of urban design qualities and their collective impact on wayfinding.

Building upon previous findings, this study hypothesizes that individuals with a well-developed cognitive map are more likely to choose shorter and more intuitive routes (Zomer et al. 2019). The study is structured around two key questions: first, how does urban configuration influence wayfinding performance? Second, does urban configuration influence wayfinding propensity? By addressing these questions, the study seeks to shed light on the complex relationship between urban design and navigational behavior. Our focus on building height as a key aspect of urban configuration is supported by studies like those of Brunyé et al. (2010) and Hölscher et al. (2011), which highlight the role of urban density and vertical elements in environmental legibility and wayfinding. By comparing wayfinding performance in these specific urban configurations, this study aims to contribute to the understanding of how the three-dimensional structure of cities affects navigation and spatial cognition. It builds on Lynch's (1960) foundational work on urban imageability and more recent research on the impact of urban form on human behavior. Despite the recognized merit of outdoor wayfinding experiments, there are inherent limitations. A common limitation is the complex nature of the experimental tasks, which, coupled with substantial labor and financial investments, make such studies challenging to conduct. Additionally, experimental scenarios and external factors are generally difficult to control (Feng et al. 2021). In light of these challenges, life-like virtual settings emerge as a viable alternative, ensuring methodological quality. This study employs a commercially available virtual setting: "Grand Theft Auto V", to overcome methodological challenges, using Los Angeles as a case study. Despite its pedestrian-unfriendliness, Los Angeles offers a diverse range of urban characteristics, making it an ideal setting for examining transitions between areas of different urban qualities. This choice also establishes a connection with Kevin Lynch's foundational observations, ensuring continuity in research.

Literature review

Perception of urban design qualities in street environments

Most urban planning and design theories traditionally emphasize the connection between environmental characteristics and performance quality indicators. Zenker and Rütter (2014) noted this connection, which is further elaborated upon by prior literature, focusing on perceptual qualities such as visual, aesthetic, and emotional aspects



that individuals recognize early in the perceptual stage (Ewing and Handy 2009; Zamanifard et al. 2019). These qualities are typically assessed through qualitative data (Gohari 2019), and research like that of Shaw (2014) has examined how emotional and social aspects interact with the design of city center streets.

Recent advancements in computer vision and street view imagery have introduced new methods for assessing perceptual qualities. For instance, Lee et al. (2022) applied deep learning techniques to analyze street view images, offering a quantitative approach to evaluate urban aesthetics. This contrasts with traditional qualitative assessments by providing more objective and comprehensive insights into urban perception.

The concept of perceived urban design qualities stems from the understanding that the built environment plays a key role in influencing walkability and wayfinding. These qualities go beyond traditional measures like neighborhood density, street connectivity, and proximity to parks, affecting choices regarding active travel and leisure activities (Ewing et al. 2006). They extend beyond urban design, bridging multidisciplinary fields including architecture, landscape architecture, park planning, and environmental psychology. This multidisciplinary nature emphasizes their role in shaping how individuals engage with their surroundings. Often discussed within the context of urban design, these qualities encompass a spectrum of perceptual and aesthetic elements of urban spaces, which are considered crucial for promoting active street life (Ewing et al. 2006). The foundational work of Ewing et al. (2006) identified several perceptual qualities essential to urban navigation and active street life, including imageability, enclosure, human scale, transparency, complexity, linkage, legibility, and coherence, which collectively influence wayfinding behavior.

The study of people's perceptions of urban design requires investigating how spatial elements influence phenomenological responses. Such spatial–human interactions are closely linked to emotional reactions (Coburn et al. 2017) and design features that are critical to the legibility of urban environments and users' wellbeing (Arthur and Passini 1992; Lynch 1960). In unfamiliar environments, the ease with which individuals understand and navigate the spatial configuration is essential. In such situations, navigators rely on various types of environmental cues to find their way (Baskaya et al. 2004). While some wayfinding challenges may arise from poor decision-making (Rodrigues et al. 2019; Stern and Portugali 1999), the design of an environment plays a direct role in how pedestrians acquire wayfinding information, with these challenges becoming more pronounced in cities due to their complexity (Meneghetti et al. 2017).

The role of city image and spatial configuration

Cities are perceived in diverse ways (Laaksonen et al. 2006) and their image is shaped by various factors. This image, as a multi-dimensional construct (Cassia et al. 2018), contributes to enhanced urban perception. Kotler et al. (1993) define city image as the collective beliefs, ideas, and impressions individuals hold about a city. Lynch (1960) expands on this by describing city image as a mental construct shaped by both objective knowledge (e.g., city facilities) and emotional elements. Lynch further points out that city image formation is influenced by configurational elements: landmarks, paths, edges, nodes, and districts, which emphasize the spatial configuration and thereby, the city's image" while also affecting wayfinding through varying perceptions (Najafpour et al. 2017).

Spatial configuration has profound implications for urban vitality and socio-physical interactions. A key aspect of this is configuration density, which includes building heights and the spaces between them, and is a critical factor. These spaces, as noted by Zerouati and Bellal (2020), are not merely voids but determinants of movement patterns and interactions. Spatial network analysis has further uncovered the morphological characteristics of urban settings (Önder and Gigi 2010), highlighting the need to explore the impact of urban configuration on wayfinding propensity. Adding to this, Mavridou et al. (2009) identified a correlation between the scale of urban settings and their affective evaluations. Notably, they found preferences for environments at both ends of the configuration density spectrum, ranging from the allure of low-rise villages to the magnetic pull of high-rise city centers. Factors such as building heights, spatial integration, and intersection attributes were found to significantly influence wayfinding decisions, underscoring the complex relationship between urban design qualities and wayfinding propensity.

Wayfinding experiments in urban design studies

Research on wayfinding within indoor or specific use settings often fails to address the complexities of urban landscapes, despite potential similarities in socioeconomic and environmental contexts (Torres-Sospedra et al. 2015). Unlike controlled indoor environments, urban environments feature intricate networks of streets, pedestrian paths, distinct landmarks, and environmental cues that collectively impact navigation. Wayfinding in these environments focuses on efficient movement through unfamiliar areas, focusing on seamless transitions from origin to destination (Brunyé et al. 2010; Chang 2013).

The complexity of wayfinding becomes more pronounced in densely populated urban areas. Factors such as indistinct boundaries (Cheung 2006), intricate layouts (Hidayetoglu



et al. 2010), inadequate environmental cues, dispersed walkable routes, communal spaces, and high visual abundance diminish urban legibility and complicate navigation. Additional challenges include difficulty developing familiarity with new areas, the absence of functional spatial hierarchies, and high population density, all of which collectively compound wayfinding difficulties. These obstacles are often linked to stress and frustration, particularly when individuals lose their way in urban environments with poorly designed spatial or geometric cues (Chang 2013).

Real-world vs. virtual environments

Generally, wayfinding studies have traditionally been conducted in both real-world and virtual environments, encompassing a spectrum from desktop simulations to fully immersive experiences. While real-world experiments offer valuable insights into human–environment interactions, they are hindered by several uncontrollable variables. Factors such as deviations in participant attention, crowd dynamics, weather conditions, and unanticipated path associations complicate data collection (Kuliga et al. 2017). Achieving complete experimental control in real-world scenarios is nearly impossible, as urban spatial environments, including squares, streets, and parks, are often characterized by imprecise or disorienting navigational cues (Stankiewicz and Kalia 2007).

Virtual environments provide a viable alternative to mitigate these challenges. Research in virtual environments has demonstrated that navigation in virtual environments serves as an adequate approximation of real-world navigation (Richardson et al. 1999). Furthermore, high-fidelity video game platforms provide cost-effective means to create vivid and interactive urban landscapes, enabling systematic and scalable spatial studies of spatial navigation (Delgrange et al. 2020). These tools allow researchers to investigate wayfinding behaviors under controlled settings while retaining ecological validity.

Advancements in urban perception and wayfinding studies

Recent technological advancements in urban perception studies have significantly improved urban perception and wayfinding research. Innovations in computer vision, deep learning, and immersive virtual reality (VR) technologies have enabled more sophisticated analyses of spatial environments. For example, Tang et al. (2024) employed street-view imagery integrated with models such as DeepLabV3+ to evaluate urban greenery, road quality, and infrastructure. This approach provided nuanced insights into spatial heterogeneity and urban liveability, offering planners large-scale, data-driven assessments of urban environments. Similarly, Xing et al. (2024) emphasized a shift in public spatial perception in the digital age, underscoring increased attention to visual aesthetics and cultural details, perception studies beyond traditional methodologies. Additionally, the growing accessibility of immersive VR technologies has further addressed challenges in real-world wayfinding research. Zhou et al. (2024) demonstrated the integration of VR with UAV panoramic imagery to evaluate youth perceptions of urban river visual features, showcasing VR's capacity for detailed spatial analysis. However, these approaches are not without limitations, as they often entail increased cognitive load and cybersickness, which can impact participant engagement and validity.

The advancements in virtual reality (VR) technologies have begun to address the challenges of real-world wayfinding research (Dong et al. 2022). The proliferation of these technologies enables new virtual experimental procedures for evaluating wayfinding behavior and spatial knowledge acquisition (Coutrot et al. 2019; Zhang et al. 2014). By providing controlled virtual environment configurations and adjustable variables, VR provides a robust platform for navigation research, validated as an adequate approximation of the real world (Richardson et al. 1999). High-fidelity video games have emerged as a cost-effective alternative, creating interactive environments suitable for spatial navigation studies (Delgrange et al. 2020). These interactive environments allow for systematic evaluation of cognitive maps, the mental representations of spatial layouts (Tolman 1948) through methods such as distance estimation, sketch mapping, route navigation, and recall tasks (Lhuillier and Gyselinck 2018).

While acknowledging the enhanced experience and immersiveness of Virtual Reality (VR) technologies, its high cognitive demands and potential for cybersickness present challenges, especially in conducting wayfinding studies (Hamad and Jia 2022). In contrast, video game-based virtual environments provide a practical alternative, leveraging prebuilt, detailed digital replicas of urban settings. This approach still holds some significant academic and practical value, especially in urban design studies as it minimizes the financial, time, and development resources required for creating custom VR environments. It also allows for the replication of a large-scale, detailed urban environment, which could be consistently used across different sessions and by different participants. Additionally, the reduced immersion of video game environments alleviates extraneous cognitive demands, allowing participants to focus on navigation tasks with little distractions as a result of physical discomfort or motion sickness (i.e., nausea, dizziness, lightheadedness) arising from use of a VR device (Hamad and Jia 2022). This may negatively impact the primary task of wayfinding.

The video game-based approach, therefore, provides an accessible, replicable, and scalable method to study urban navigation within a controlled yet complex virtual setting. It



is noteworthy that while less immersive than advanced VR technologies, it strikes a critical balance between realism and practicality. This methodology supports the investigation of urban wayfinding within a complex, controlled, scalable, and replicable setting.

Experiment design and analytical framework

This study adopts a video game-based virtual environment methodology for the experiment. The experimental setup bears a close resemblance to that of Delgrange et al. (2020) with modifications to the approach adopted for the purpose of urban design research. The setup allows a high degree of control and manipulation of urban and environmental parameters across different conditions within the VR game setting. Data collected from the questionnaire survey will be analyzed using analysis of variance (ANOVA) and ordinary least squares regression.

Rationale for using GTA V as a research platform

This study employs the virtual environment of Grand Theft Auto V (GTA V) for urban design research, using its detailed and interactive digital world as an effective alternative to high-end virtual reality technologies. It is essential to clarify that this approach does not constitute a fully immersive virtual reality (VR) experiment in the strictest sense. Rather, it leverages the meticulously crafted and interactive digital environment of GTA V's Los Santos, which offers a practical and accessible platform for exploring spatial relationships and urban dynamics. As Pearson (2024) notes, video game environments like GTA V provide digital cities that capture the structural and cultural essence of urban spaces, making them suitable for investigating urban design concepts.

This methodology aligns with previous urban studies that utilized game-based environments, capitalizing on their accessibility, scalability, and ability to evoke meaningful cognitive and perceptual responses from participants, even in semi-realistic settings (Puyana Romero et al. 2016; Zhou et al. 2024). While fully immersive VR technologies may offer more realistic experiences (Kwon et al. 2024), they are often accompanied by significant challenges such as higher costs, development time, and participant discomfort due to cybersickness (Song and Li 2024). In contrast, the use of GTA V provides a cost-effective and flexible platform for controlled experimentation and detailed analysis of urban environments.

Methodological strengths of video game environments

The use of Grand Theft Auto V (GTA V) as a research tool in urban design studies highlights the trade-offs between realism and practicality. This methodological choice reflects a strategic prioritization of research goals, focusing on navigational behaviors in detailed yet manageable environments over full immersion. During exploratory phases of research, where broad patterns and behaviors are being investigated, this approach provides an efficient and effective solution. For example, video game environments allow for repeated experimentation under identical conditions, enhancing the reliability of findings. Additionally, they offer researchers the ability to simulate transitions between different urban configurations, such as high-rise and low-rise settings, which would be difficult to replicate in real-world studies.

The Virtual City of Los Santos, the virtual city in GTA V, is a meticulously crafted model of Los Angeles that incorporates a diverse range of urban features, from dense downtown areas to sprawling suburban neighborhoods (Ameli and Mousavi Haghshenas 2023). The photographic accuracy of the virtual city's spatial relationships and urban dynamics (Alephograph, 2024). However, it is important to acknowledge that while GTA V's game engine offers impressive visual fidelity, it does not fully capture the nuanced soundscapes and everyday scenes across various urban forms and geolocations. The game's audio design prioritizes dramatic elements over realistic ambient sounds, potentially limiting its use in studies that focus on subtle acoustic cues for navigation and urban experience.

Addressing the concern about realism at the street level, GTA V employs advanced graphical techniques such as deferred rendering and high dynamic range (HDR) lighting to enhance visual fidelity (Courrèges 2015). These techniques contribute to the immersive quality of its urban scenes by offering realistic lighting, shadows, and reflections. Furthermore, studies have demonstrated that virtual environments do not need to achieve perfect realism to be effective for urban research. For example, Puyana Romero et al. (2017) and Zhou et al. (2024) highlight that even stylized or semi-realistic environments can evoke meaningful cognitive and perceptual responses from participants. Furthermore, Ameli and Mousavi Haghshenas (2023) argue that GTA V's non-linear gameplay and multiple pathways enhance its value for urban studies by allowing participants to explore diverse spatial configurations.

Despite several advantages, GTA V is not without certain limitations. When compared to modern alternatives such as 360° video in real urban environments, It does not fully achieve realistic representation (Kwon et al. 2024; Xing et al. 2024). Although immersive VR technologies and panoramic videos offer a higher degree of realism, they are often accompanied with significant drawbacks, including increased costs, extended development times, and participant discomfort due to cybersickness. GTA V serves as a practical alternative by striking a balance between visual fidelity, accessibility and scalability. Its ability to replicate



complex urban environments at a fraction of the cost and effort required for custom-built VR models makes it an invaluable resource for urban design research. This approach is consistent with previous findings that highlight the trade-offs between realism and practicality in virtual environment research (Song and Li 2024). Although our study utilized a virtual environment based on Grand Theft Auto V's Los Santos, there are advantages to employing advanced tools like Google Street View imagery or immersive VR headsets. These technologies offer a high degree of realism, allowing researchers to capture multisensory and dynamic interactions within real-world contexts. For instance, studies by Dong et al. (2022) and Qiu et al. (2022) demonstrate how integrating subjective perceptions with objective data from open sources can yield comprehensive insights into urban design quality. However, the controlled environment of Los Santos enabled us to systematically manipulate specific urban configuration, a capability that is often difficult to achieve with real-world data or immersive technologies. This combination of experimental control and ecological validity ensures that our findings contribute significantly to understanding how urban configurations affect wayfinding behavior.

Participants

Participants in this research are 50 Urban Design field students from three universities namely, Chung-Ang University, Konkuk University and Seoul National University in Seoul, South Korea. The ages of participants range between 18 and 40 years and comprised of 28 male and 22 female participants. A snowball sampling method was adopted for this study. Initial participants are recruited by advert within the Urban Design Departments through KakaoTalk SNS. After they respond with the willingness to participate in the experiment, they are asked to nominate other suitable subjects known to them until the desired sample size of 50 participants is achieved. From the literature survey, the median sample size for wayfinding experiments is 32 participants (Zomer et al. 2019). Experiments were conducted between July and August 2021.

Virtual reality-based wayfinding experiment design and process

To comprehensively address the research questions, we employed a projector-based Virtual Reality (VR) experiment. The experimental setup for the wayfinding task was within a controlled laboratory environment. The core instruments comprised a Sony PlayStation 4 console, equipped with a copy video game "Grand Theft Auto V" (GTA V). Visuals from the virtual environment were projected onto a large screen using an overhead-mounted projector, ensuring an immersive navigational experience for the participants. The interface between the participant and the virtual environment was facilitated by a PlayStation navigation controller, selected for its intuitive design and ease of use. Lastly, a digital timer was utilized to accurately record the duration of each wayfinding task. Participants were comfortably seated in a consistent position throughout the experiment to maintain a standard viewpoint and interaction with the virtual environment. The projector overhead displayed the virtual environment from the participant's perspective, similar to the visual field one would experience while navigating an actual urban setting. The experiments were conducted within the confines of a dedicated study lab, where the instruments were securely installed to ensure stability and consistency across all sessions. All sessions took place during daytime hours.

Throughout the wayfinding tasks, participants received navigational instructions from a research assistant situated to their right. This setup was intended to replicate the role of a navigational assistant in real-world scenarios. Notably, there were no time constraints imposed on the participants, allowing them to engage with the wayfinding task at a natural and comfortable pace without the pressure of a deadline. This approach aimed to mirror the typical dynamics of urban navigation, wherein time restrictions are often absent. The experiment employed a simulated virtual environment of the City of Los Angeles, California, allowing participants to engage in wayfinding tasks across three distinctive urban configurations: Pillbox Hill (high-rise), Little Seoul (mid-rise), and Vinewood (low-rise).

Upon engaging in the virtual wayfinding task, participants were placed in front of a projected environment operated by the PlayStation console. For this task, they were required to navigate through three routes of equal distances in the aforementioned virtual neighborhoods. While navigating, participants received guidance from a landmark assistant's instructions for the first phase (i.e., route learning). For instance, they were directed with cues like "Go along it on the right, stop at the intersection". The initial wayfinding task is structured to measure the total time taken to navigate from a specified starting point to a destination and back, following a direct route designated by the experimenters (route following). If the primary guided path isn't intuitive, they can choose a preferred route. It's hypothesized that those with a stronger cognitive map will choose shorter or more intuitive routes. Previous studies suggest participants with better orientation and a developed cognitive map tend to choose routes with shorter travel distance and time, but not necessarily higher travel speed (Zomer et al. 2019). However, for the second phase of the task (i.e., route following), participants were to rely on their memory. To aid them in recalling the destination, participants were provided with a photo card

depicting their endpoint. The completion of each route was marked by reaching the designated destination and then returning to the starting point. A visual representation of a typical route is presented in Fig. 2, offering a glimpse into the participants' journey led by the landmark navigation assistant.

To ensure participants had a foundational understanding of the variables involved, prior to the main experiment, they were presented with educational material as a part of pre-experiment orientation. This orientation involved viewing a short video, which was accompanied by a PowerPoint presentation. This video, created by a professor from our department, elucidated the 13 experimental variables pertinent to this study. The concepts of perceived urban design qualities were sourced from a manual that provided guidance on the objective measurement of urban street environments (Clemente and Ewing 2005). Furthermore, to effectively clarify the city image elements under focus, the video integrated definitions from Lynch (1960).

After concluding the virtual wayfinding journey, participants were directed to a questionnaire, formatted using a five-point Likert scale. This survey aimed to gauge participants' perceptions and the importance they attributed to city image elements and perceived urban design qualities.

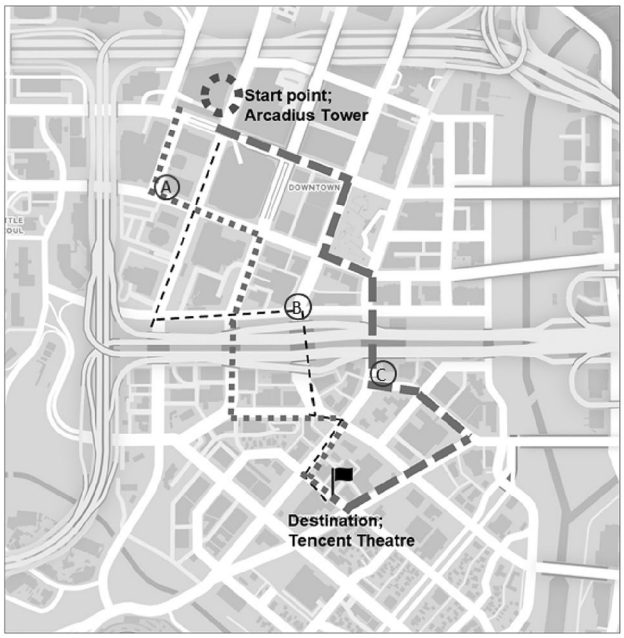

Fig. 2 Map representations of multiple route choices in Pillbox Hill, i.e., routes A–C

Measures for the experiment

Dependent variables

The total amount of time it takes one to arrive at a destination during a wayfinding task has been used as an important variable in wayfinding research (O'Neill 1991). However, because one of the goals of this research was to investigate improvements in wayfinding performance, we used a variation of this variable. This is because a reduction in second wayfinding time compared to the first wayfinding time shows more efficient wayfinding. As such, in our model, we adapted the dependent variable to be the difference between the length of time it took participants to complete the first and second wayfinding tasks (Fig. 3).

Independent variables

This study utilizes city image elements as independent variables, adopting the framework established by Kevin Lynch in *The Image of the City* (1960). The elements, namely paths, edges, nodes, districts, and landmarks, are employed as key components for analyzing urban environments. To gain a deeper understanding of perceived urban design qualities, this research also incorporates operationalized measures from Ewing and Handy's (2009) study, *Measuring the Unmeasurable*. These measures include abstract qualities such as imageability, enclosure, human scale, transparency, complexity, linkage, legibility, and coherence. Together, these elements form a comprehensive framework for evaluating the physical and perceptual attributes of street environments in relation to wayfinding tasks.

Control variables were carefully selected based on factors likely to influence wayfinding ability. Socio-demographic variables such as gender and age were prioritized, as previous studies have established correlations between these variables and wayfinding performance. For instance, gender differences in spatial navigation have been highlighted by Munion et al. (2019) and Lawton and Kallai (2002), while age-related differences in spatial abilities are discussed by Kirasic (2000), Taillade et al. (2016), and Zomer et al. (2019). To account for variations in participants' educational backgrounds, a "university" variable was incorporated, given that students were drawn from three institutions with potentially distinct curricula. Additionally, the snowball sampling method used for participant recruitment necessitated the inclusion of an ID variable to control for potential biases introduced by this technique.

Methodology for capturing urban design qualities

The measurement of perceived urban design qualities in this study builds on the methodology developed by Ewing and

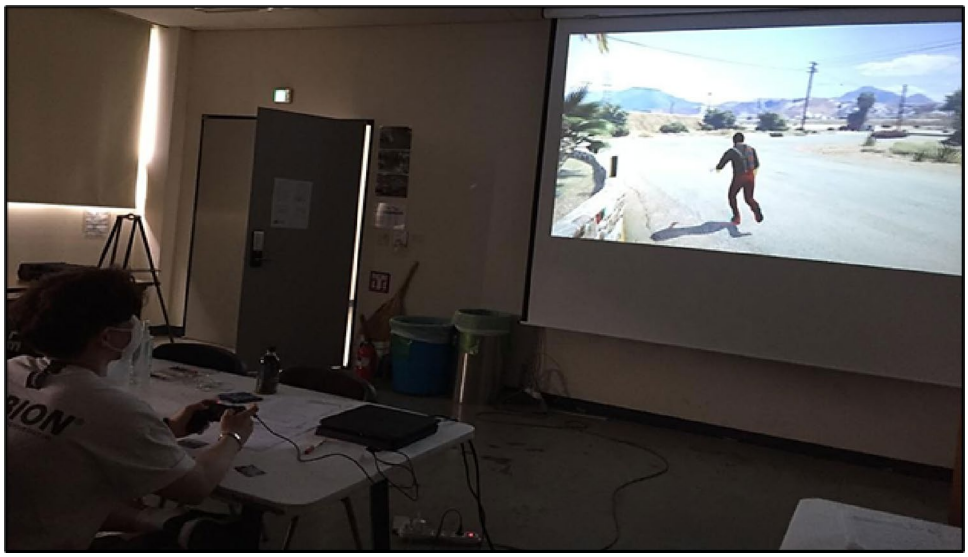

Fig. 3 Setup of the wayfinding task at Chung-Ang University. The projector overhead displays the VR environment

Handy (2009), adapted for use within a virtual environment. Using Grand Theft Auto V's Los Santos as a proxy for Los Angeles, in-game images were captured at pedestrian eye level to simulate realistic perspectives. These images represented a range of urban configurations, including low-rise and high-rise settings, selected to capture a variety of urban design qualities within the video game environment. This systematic adaptation maintains methodological consistency with previous urban perception studies while leveraging the scalability of virtual environments (Ameli et al., 2023).

To achieve a comprehensive representation of the urban landscape, the visual survey was designed to incorporate two complementary elements: first, a systematic route-based imagery. Second, distinct landmark imagery. For the route-based imagery, a "serial vision" approach inspired by Cullen (1961) was utilized, capturing images at regular intervals (every 100 virtual meters) along key routes traversing low-rise and high-rise areas. This method highlights participants' sequential navigation experience and captures the changing perceptions of urban spaces along a route. For the landmark imagery, visually prominent and structurally significant were selected based on Lynch's (1960) framework for imageability and Sorrows and Hirtle's (1999) criteria for effective landmarks. Additionally, this methodology ensures consistency in visual stimuli across participants. It also enhances the internal validity of the ratings and aligns with best practices in visual perception research. Examples include skyscrapers, unique architectural features, and prominent intersections, which serve as critical reference points for wayfinding. Together, these two components simulate real-world wayfinding experiences within the constraints of the virtual environment.

After completing the wayfinding task, participants were presented with the systematically captured and printed images (photo cards) as visual stimuli for the survey. They were asked to rate various urban design qualities on a five-point Likert scale, adhering to the definitions established by Ewing and Handy (2009). The evaluated qualities included imageability, enclosure, human scale, transparency, and complexity, reflecting both abstract and observable attributes of urban spaces. The use of static imagery for assessing urban design qualities has been validated in prior research (Nasar, 1994; Stamps III 2005), supporting the reliability of this approach for capturing participants' perceptions of urban environments.

The analysis of participants' ratings combined with wayfinding performance data enabled us to predict and evaluate the relationship between perceived urban design qualities and navigational behavior. By correlating subjective evaluations of urban design qualities with objective wayfinding outcomes, this study contributes to the understanding of how spatial configurations influence wayfinding propensity. This approach ensures that perceived scores are grounded in empirical observations, addressing concerns about their predictive validity (Brunyé et al. 2010; Hölscher et al. 2011) (Figs. 4, 5, 6).

Results

In this study, we employed two primary statistical analyses: ANOVA and multiple regression analysis. ANOVA is used to determine the statistical relationship between continuous variables. This technique aims to discern the similarity or disparity between two sets of rankings. The correlation coefficient resulting from ANOVA ranges from -1 to 1, where the sign indicates direction (positive or negative) and the magnitude indicates strength. For interpretation, near ± 1

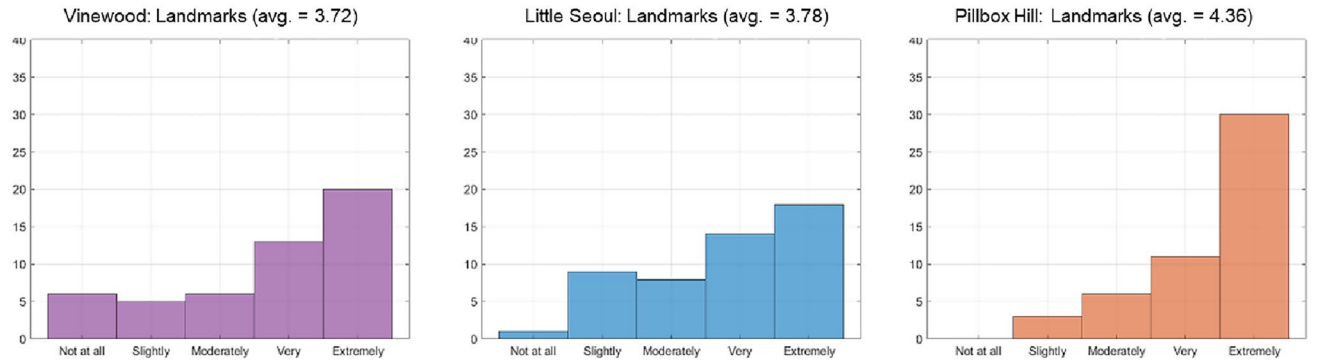

Fig. 4 Likert scale rating for landmarks for 150 cases across three sites

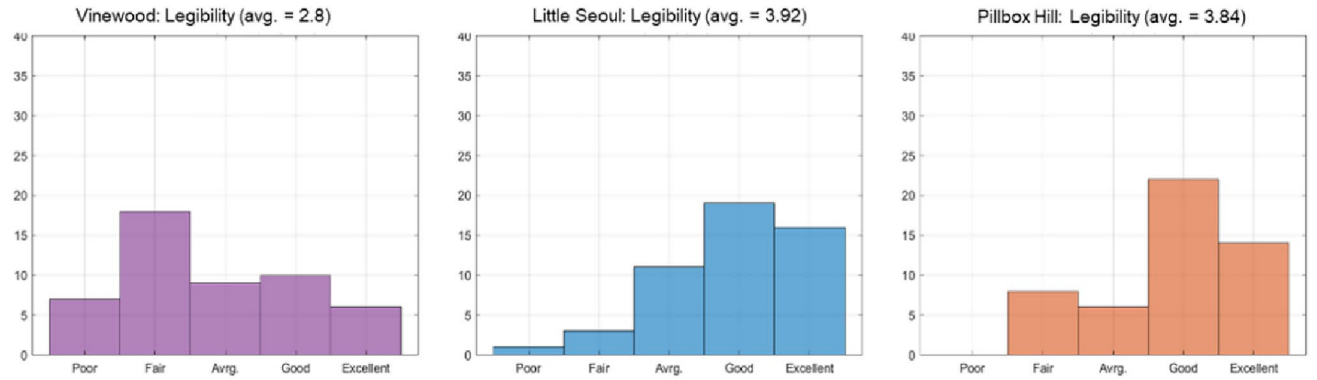

Fig. 5 Likert scale rating for legibility for 150 cases across three sites

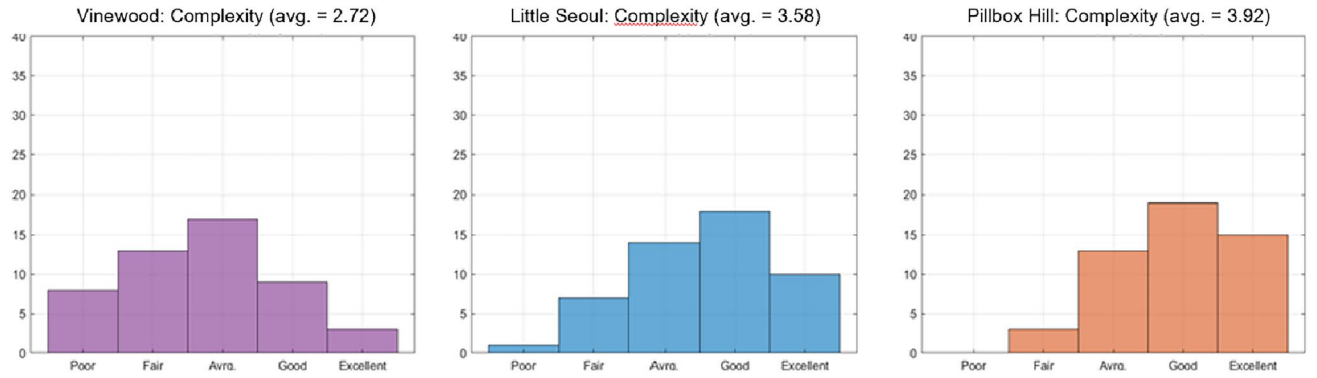

Fig. 6 Likert scale rating for complexity for 150 cases across three sites

signifies a perfect correlation; between ± 0.50 and ± 1 indicates a strong correlation; ± 0.30 to ± 0.49 indicates a moderate correlation; and below ± 0.29 signifies a weak correlation.

Multiple regression analysis, on the other hand, explores the relationships among multiple variables. Specifically, it examines the association between a dependent variable and multiple explanatory (or independent) variables. In our study, the regression model was constructed with the dependent variable being the difference between the first wayfinding time (route learning) and the second wayfinding time (route following), factoring in other independent variables. To deepen our understanding of the participants' spatial knowledge improvement across different urban configurations (low-rise, mid-rise, and high-rise), we employed this regression analysis. While several variables were available,



Fig. 7 Pairwise street-level images providing a clear visual demonstration of the virtual environment's capacity to replicate real-world urban features

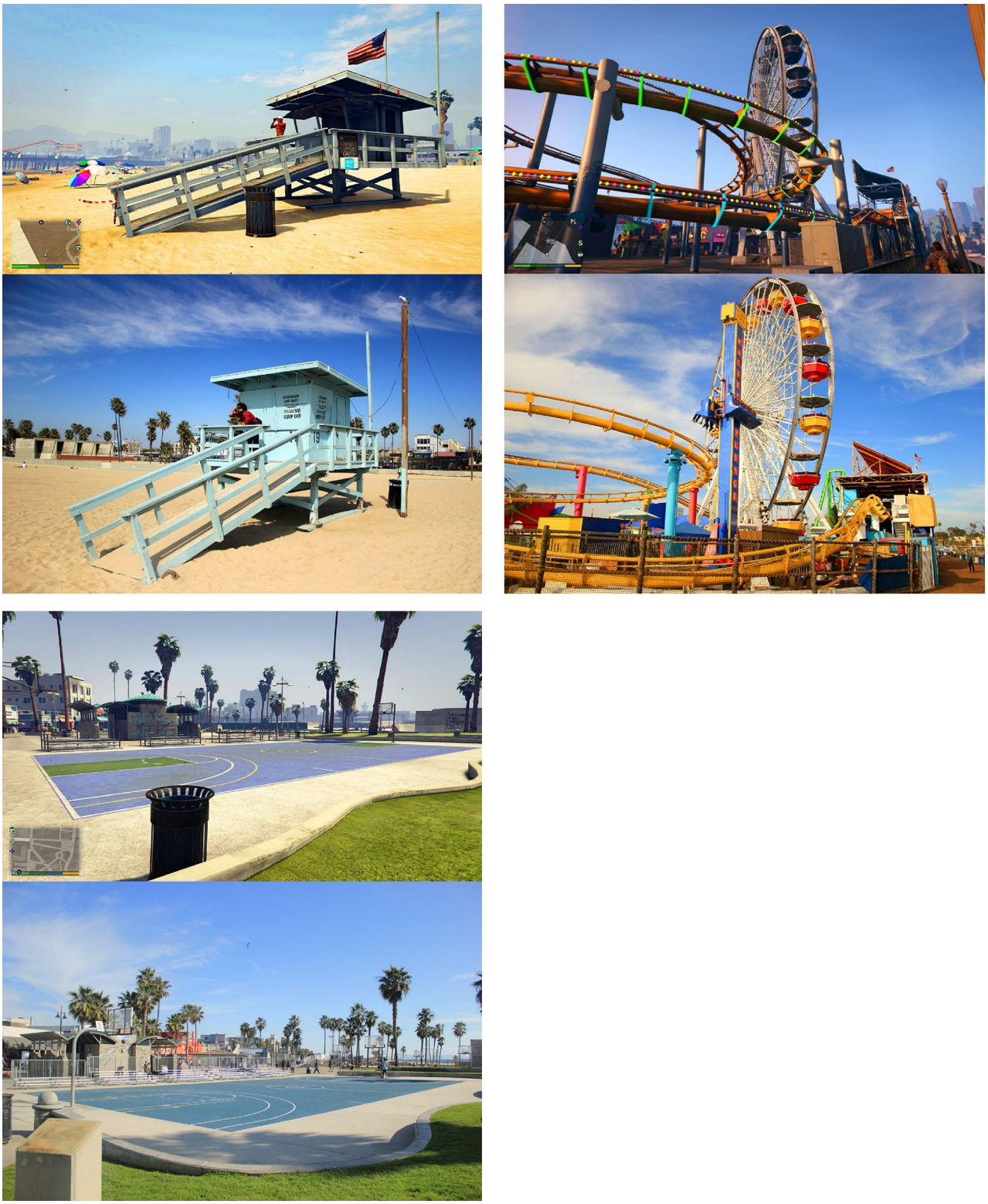

Fig. 7 (continued)

Table 1 Combined results of ANOVAs for average of first wayfinding time and for second wayfinding time in three environments

	First wayfinding time					Second wayfinding time			
	Site	Significance	*N*	Mean (s)	Standard deviation	Significance	*N*	Mean (s)	Standard deviation
Pillbox	Vinewood	0.934	50	672.580	238.409	0.098	50	523.700	214.600
	Little Seoul	**0.000***				**0.003***			
Little Seoul	Pillbox Hill	0.934	50	657.920	246.906	**0.003***	50	651.400	222.200
	Vinewood	**0.000***				**0.000***			
Vinewood	Pillbox Hill	**0.000***	50	478.520	106.405	0.098	50	454.300	95.800
	Little Seoul	**0.000***				**0.000***			
	F					*F*			
Between groups	13.564	**0.000***				13.28	**0.000***		

With respect to average wayfinding time, *indicates that mean differences between two groups are significant at $\alpha = 0.05$ (result from one-way ANOVA and post hoc multiple comparison analysis using HSD method). For the purposes of this study, average wayfinding time is defined as the length of time it takes to navigate from the starting point to destination and back

Bold values indicate statistically signifcant results (meaningful differences)

we focused on three key variables based on their relevance and anticipated impact on the dependent variable, ensuring the analysis was targeted and meaningful (Fig. 7).

Wayfinding performance according to configuration (results of ANOVA)

The primary aim of the ANOVA analysis was to discern differences in wayfinding performance, measured by wayfinding time, across varying urban configurations. The results have been detailed in Table 1.

Starting with the first wayfinding time in Table 1, it illustrates the ANOVA results comparing the initial wayfinding times across the three urban configurations: Pillbox Hill, Little Seoul, and Vinewood. The recorded *F* value of 13.564, which is notably greater than 4, suggests significant differences in wayfinding times across these sites. The subsequent post hoc analysis, utilizing Tukey's method, revealed significant disparities in the initial wayfinding times between Pillbox Hill and Little Seoul (0.000) and between Vinewood and Little Seoul (0.000). However, no substantial difference was identified between Pillbox Hill and Vinewood during the initial phase.

In addition, the absolute wayfinding times for the second round were analyzed using ANOVA to evaluate final performance (Table 1). The results ($F = 13.28$, $p < 0.001$) showed significant differences between configurations, with Vinewood (454.3 s) being the fastest, followed by Pillbox Hill (523.7 s), and Little Seoul (651.4 s). Post hoc tests confirmed that Vinewood performed significantly better than Little Seoul ($p < 0.001$), and Pillbox Hill was also significantly faster than Little Seoul ($p = 0.003$), although there was no significant difference between Vinewood and Pillbox Hill ($p = 0.098$).

Table 2 Results of ANOVAs for improved wayfinding time in three environments (initial-subsequent)

	Improved wayfinding time				
	Site	Significance	*N*	Mean (s)	Standard deviation
Pillbox	Vinewood	0.002*	50	− 148.860	225.536
	Little Seoul	**0.006***			
Little Seoul	Pillbox Hill	**0.002***	50	− 6.490	234.583
	Vinewood	0.898			
Vinewood	Pillbox Hill	**0.006***	50	− 24.220	16.807
	Little Seoul	0.898			
	F				
Between groups	7.507	**0.001***			

With respect to average wayfinding time, *indicates that mean differences between two groups are significant at $\alpha = 0.05$ (result from one-way ANOVA and post hoc multiple comparison analysis using HSD method). For the purposes of this study, average wayfinding time is defined as the length of time it takes to navigate from the starting point to destination and back

Bold values indicate statistically signifcant results (meaningful differences)

Turning to Table 2, it provides insights into the participants' improvement in wayfinding performance. Here, the measure was the difference between the initial and subsequent wayfinding times. A negative value indicates an enhancement in wayfinding performance, signifying a reduced time taken during the second attempt. The *F* statistics affirm significant variations in the improvement levels across the urban configurations. Specifically, Pillbox Hill, the high-rise environment, showcased a marked improvement in wayfinding times. In contrast, both the low-rise (Vinewood) and mid-rise (Little Seoul) settings did not demonstrate substantial enhancements. This observation is further supported by the statistical differences in improved wayfinding times between Pillbox Hill and Vinewood ($p = 0.002$) and between Pillbox Hill and Little Seoul ($p = 0.006$). Notably, no discernible difference was seen between Little Seoul and Vinewood ($p = 0.898$).

In examining the underlying factors, one might consider the distinct urban features of each environment. Pillbox Hill, characterized by its high-rise structures and distinct urban elements, might present a more pronounced and memorable cityscape for participants, as evidenced by the high average rating of 4.36 for landmark perception. Conversely, Vinewood, a predominantly low-rise residential area, surprisingly scored highest (avg. = 3.54) in human scale perception, emphasizing the multifaceted nature of urban design and wayfinding experiences.

The notable statistical difference between Pillbox Hill and Vinewood could stem from varying perceptions of the 13 study variables across the three urban configurations. While Vinewood predominantly features low-rise residential buildings, Pillbox Hill resonates more strongly with pedestrians due to its high-rise architecture, marked by distinct shapes, colors, arrangements, and unique buildings. Participants' perception ratings for landmarks in Pillbox Hill were notably high (avg. = 4.36). Interestingly, Vinewood, a low-rise area, had the highest average rating for human scale (avg. = 3.54). These observations are preliminary and should be approached with caution. Further insights will be provided by the subsequent regression analysis.

Configuration-specific wayfinding improvements (results of multiple regression analyses)

The objective of the regression analysis was to further investigate participants' level of improvement in their spatial knowledge during the wayfinding activities across the low-rise, mid-rise, and high-rise urban areas. The regression model is fixed with the dependent variable as the first wayfinding time (i.e., route learning) minus the second wayfinding time (i.e., route following) in addition to other independent variables. Results of two models are presented. An original model containing all experiment variables and a final model containing only variables that were expected to be statistically meaningful. The results of the final model showed legibility as a negative figure. This negative value denotes reduced wayfinding time; that is, this signifies an improvement as participants tended to improve their wayfinding abilities when legibility was higher. This also corresponds to the higher Likert scale rating of legibility in the questionnaire survey by participants. There was a similar finding for the human scale; that is, participants that gave higher Likert scale ratings for the importance of human scale to their wayfinding task tended to show more significant wayfinding improvements since the value of the coefficient for human scale was negative.

Participants also showed significant improvement in Pillbox Hill compared to the other two sites. Interestingly, this coincides with the findings from the histogram, which showed that the legibility was highest in Pillbox Hill. This may be because well-defined street patterns which typically characterize such high-rise urban areas as Pillbox Hill are usually remembered much more easily than non-defined organic patterns that characterize the mid and low-rise areas. Based on studies by Gell (1985) and Isotomin and Dwyer (2009), during wayfinding activities in street environments, people are able to encode the geometric structure of the built environment in their minds in areas with well-defined and legible patterns. For instance, streets designed with clear patterns such as a grid or star shape can be better perceived compared to non-defined patterns. Another variable that showed significance is whether participants chose a different route to return to the starting point ($p = 0.003$). This demonstrated improvement and implied an increase in spatial knowledge.

To delve deeper into the assessment of actual wayfinding performance, an additional regression analysis was conducted with the absolute second wayfinding time as the dependent variable (Table 3). The final model confirmed that legibility ($p = 0.0027$), human scale ($p = 0.0368$), and enclosure ($p = 0.0216$) significantly reduced wayfinding time, consistent with their role in improving performance. Participants in Pillbox Hill also exhibited faster wayfinding times ($p = 0.0129$), reinforcing the high-rise environment's advantage in facilitating efficient navigation. The choice of a different route back to the starting point further decreased ($p = 0.0058$), indicating enhanced spatial knowledge.

The results of the control variables are generally as expected which implies that the experimental conditions were well-maintained, minimizing confounding influences.

Table 4 presents the results of multiple regression analysis for the original model (all parameters) and final version (seven parameters) for Model 1 (first wayfinding time). There are a total of seven parameters that are expected to be statistically meaningful with the first travel time in Model 1. Deeper analysis (Final model 1 in Table 2) with only those



Table 3 Combined results of multiple regression analysis for original version (all parameters) and final version (significant parameters) for second wayfinding time

All parameters (original)	Model 2 (all parameters)			Model 2 (significant parameters)		
	B	*t* value	*p* value	*B*	*t* value	*p* value
Constant	600.127	2.512	**0.013***	580.394	3.827	**0.000**
Participant ID	0.583	0.419	0.689			
Virtual environments						
High-rise VR environment (Pillbox Hill)	−50.236	−2.147	**0.037***	−45.781	−2.536	**0.013***
Mid-rise VR environment (Little Seoul)	100.472	1.829	0.073	90.153	1.914	0.059
Socio-demographics of participants						
Gender (female = 1)	10.315	0.328	0.763			
Participant's age from 20 to 25	−15.692	−0.514	0.615			
Participant's age from 30 to 40	20.841	0.627	0.548			
Participant grew up in either a high-rise or low-rise building	5.194	0.213	0.840			
Participant has previous VR experience	−20.378	−0.716	0.482			
City image elements						
Likert scale rating of paths	5.627	0.319	0.762			
Likert scale rating of edges	3.451	0.227	0.839			
Likert scale rating of districts	−2.813	−0.126	0.918			
Likert scale rating of nodes	4.392	0.218	0.8395			
Likert scale rating of landmarks	−10.564	−0.529	0.616			
Perceptive urban design qualities of street environments						
Likert scale rating of the human scale	−38.129	−2.034	**0.046***	−30.472	−2.119	**0.037***
Likert scale rating of legibility	−50.738	−2.826	**0.006***	−45.316	−3.042	**0.003***
Likert scale rating of coherence	10.927	0.518	0.615			
Likert scale rating of complexity	8.264	0.413	0.688			
Likert scale rating of imageability	5.738	0.314	0.762			
Likert scale rating of enclosure	−40.591	−2.238	**0.028***	−35.829	−2.347	**0.021***
Likert scale rating of transparency	−3.142	−0.219	0.840			
Likert scale rating of linkage	7.395	0.426	0.687			
Participant's wayfinding route back to starting point is modified	20.614	0.638	0.547			
Participant's wayfinding route to destination is modified	15.873	0.529	0.616			
Participant's wayfinding route to destination is different	−10.426	−0.417	0.687			
Participant's wayfinding route back to starting point is different	−130.258	−2.519	**0.013***	−120.647	−2.814	**0.006***
Adjusted R2	0.230			0.250		

The asterisk (*) indicates coefficients that are significant at the $\alpha = 0.05$ level or better (total observations 150)

Bold values indicate statistically signifcant results (meaningful differences)

seven parameters showed two that are statistically meaningful: Pillbox Hill ($p = 0.001$) and enclosure ($p = 0.009$). However, some may have possibilities of marginal significance; for instance, human scale ($p = 0.051$).

From the Model 1 (original) of Table 2, there is a positive coefficient for the high-rise area variable (204.353). This result was anticipated. The likely reason for this is that the participants were instructed to take their time to familiarize themselves with the environment by making as many visual connections as possible during the first wayfinding task (the route-learning phase). The reason for this instruction was that although the first wayfinding task was guided, the second phase was unguided and thus required participants to work from memory.

With regard to enclosure ($p = 0.009$) in Model 1 (final), this value implies that an increase in the perception of enclosure results in a decrease in travel time. The significant impact of enclosure may be the result of the level of arousal: moderately enclosed open spaces are ambiguous and thus increase one's arousal level (Shulin et al. 2014). This may lead one to believe that an increase in arousal due to enclosure may lead to faster wayfinding times. Further, according to Cullen (1961), "enclosure is, perhaps, the most powerful, the most obvious, of all the devices to instill a sense of position, of identity with the surroundings." From

Table 4 Combined results of multiple regression analysis for original version (all parameters) and final version (seven parameters) for Model 1 *first wayfinding time*

	Model 1 (original)			Model 1 (final)		
	B	*t* value	*p* value	*B*	*t* value	*p* value
Constant	181.485	0.718	0.474	432.122	4.972	0.000
Participant ID	1.711	1.300	0.196			
Virtual environments						
High-rise VR environment (Pillbox Hill)	204.353	1.502	0.136	145.596	3.275	**0.001***
Mid-rise VR environment (Little Seoul)	−93.848	−1.192	0.236			
Socio-demographics of participants						
Gender (female = 1)	−77.766	−1.773	0.079	−60.762	−1.736	0.085
Participant's age from 20 to 25	−28.426	−0.635	0.527			
Participant's age from 30 to 40	16.461	0.307	0.760			
Participant grew up in either a high-rise or low-rise building	10.543	0.228	0.820			
Participant has previous VR experience	−3.484	−0.09	0.928			
City image elements						
Likert scale rating of paths	6.415	0.369	0.713			
Likert scale rating of edges	21.188	1.205	0.231			
Likert scale rating of districts	5.792	0.384	0.702			
Likert scale rating of nodes	6.518	0.363	0.717			
Likert scale rating of landmarks	18.908	1.133	0.259			
Perceptive urban design qualities of street environments						
Likert scale rating of the human scale	29.494	1.573	0.118	35.601	1.967	0.051
Likert scale rating of coherence	53.285	2.331	0.021*	34.953	1.702	0.091
Likert scale rating of complexity	40.715	2.184	0.031*	15.032	0.879	0.381
Likert scale rating of imageability	−30.818	−1.498	0.137			
Likert scale rating of enclosure	−41.882	−2.179	0.031*			
Likert scale rating of transparency	0.066	0.004	0.997			
Likert scale rating of linkage	−28.056	−1.370	0.173			
Likert scale rating of legibility	−2.551	−0.136	0.892			
Participant's wayfinding route to destination is different	126.13	1.935	0.055	109.667	1.943	0.054
Participant's wayfinding route to destination is modified	54.221	0.735	0.464			
Participant's wayfinding route back to starting point is modified	−52.714	−0.688	0.493			
Participant's wayfinding route back to starting point is different (*Reference: Route back is the same as the original route*)	−11.393	−0.173	0.863			
Adjusted R^2	0.215			0.119		

The asterisk (*) indicates coefficients that are significant at the $\alpha = 0.05$ level or better

Bold values indicate statistically signifcant results (meaningful differences)

the general sample, the perception of enclosure (avg. = 3.08) was found to be highest at Pillbox Hill. Enclosure, which symbolizes the idea of hereness (Alexander 1977), may lead to an increased understanding of this kind of space. In Stamps and Smith (2002), pictures of the City of Paris suggest that an individual's perception of enclosure is positively related to how much the area is surrounded by walls and negatively related to how much ground is visible, the depth of view, and the number of sides open at the front.

Table 5 details the results of the original version of Model 2 with all the variables and the final version, which shows that there are five parameters that are expected to be statistically meaningful (second wayfinding time first wayfinding time). However, further analysis with only those five parameters as seen in Model 2 (final) in Table 5 reveals that they are all statistically meaningful (second wayfinding time–first wayfinding time).

Legibility (0.003), which had a significant impact, refers to the possibility for participants to organize the environment within an imageable and coherent pattern. The characteristics of a space provide an individual with an understanding of its form by allowing them to imagine cognitive maps that facilitate wayfinding (Herzog and Leverich 2003). This is a process that evolves with the deriving of spatial information



Table 5 Combined results of multiple regression analysis for original version (all parameters) and final version (five parameters) for Model 2 (*second wayfinding time–first wayfinding time*)

	Model 2 (original)			Model 2 (final)		
	B	*t* value	*p* value	*B*	*t* value	*p* value
Constant	328.154	1.206	0.230	269.106	4.072	0.000
Participant ID	−0.922	−0.600	0.549			
Virtual environments						
High-rise VR environment (Pillbox Hill)	−243.172	−1.520*	0.131	−151.549	−4.193	**0.000***
Mid-rise VR environment (Little Seoul)	−10.593	−0.117	0.907			
Socio-demographics of participants						
Gender (female = 1)	−0.084	−0.002	0.999			
Participant's age from 20 to 25	35.307	0.843	0.401			
Participant's age from 30 to 40	49.922	0.997	0.321			
Participant grew up in either a high-rise or low-rise building	−11.078	−0.256	0.798			
Participant has previous VR experience	−70.665	−1.962	0.052	−66.57	−2.23	**0.027***
City image elements						
Likert scale rating of paths	7.566	0.460	0.646			
Likert scale rating of edges	6.571	0.400	0.690			
Likert scale rating of districts	−3.709	−0.263	0.793			
Likert scale rating of nodes	−5.505	−0.325	0.746			
Likert scale rating of landmarks	−11.864	−0.758	0.450			
Perceptive urban design qualities of street environments						
Likert scale rating of the human scale	−38.661	−2.209	0.029*	−29.463	−2.041	**0.043***
Likert scale rating of legibility	−55.733	−3.096	0.002*	−37.82	−2.983	**0.003***
Likert scale rating of coherence	16.712	0.769	0.444			
Likert scale rating of complexity	9.924	0.554	0.580			
Likert scale rating of imageability	7.197	0.366	0.715			
Likert scale rating of enclosure	2.891	0.159	0.874			
Likert scale rating of transparency	−11.448	−0.661	0.510			
Likert scale rating of linkage	9.849	0.515	0.607			
Participant's wayfinding route back to starting point is modified	59.971	0.836	0.405	−142.45	−3.006	**0.003***
Participant's wayfinding route to destination is modified	83.055	1.200	0.233			
Participant's wayfinding route to destination is different	29.229	0.466	0.642			
Participant's wayfinding route back to starting point is different	−134.728	−2.157	0.033*			
Adjusted R^2	0.204			0.244		

The asterisk (*) indicates coefficients that are significant at the $\alpha = 0.05$ level or better (total observations 300)

Bold values indicate statistically signifcant results (meaningful differences)

from the environment and by mentally processing that information and using it for the wayfinding task. It can be argued that this process is enhanced the more a person undertakes a certain route each time, thereby continually adding to the obtained information.

With regard to human scale, this differed greatly across the three sites with the highest average perception in Vinewood (avg. = 3.54) and lowest in Pillbox Hill (avg. = 2.5). Urban designers offer differing definitions of human scale. Alexander et al. (1977) state that any building over four stories tall is beyond human scale. Blumenfeld (1953) sets it at three stories. Many site-specific factors can account for human scale being statistically significant. Arnold (1993) found that tall buildings and wide streets typically intimidate pedestrians. This characteristic of intimidation may justify an increase in walking speed due to a sense of intimidation in a high-rise area.

In summary, the results indicate that as the configuration increases from low-rise to high-rise, people tend to perceive design qualities and city image elements more. Additionally, they tend to perform better in wayfinding in

terms of performance as measured by absolute wayfinding time.

Discussion and conclusions

This study aimed to investigate the relationship between perception of city image elements, urban design qualities, and wayfinding performance under different urban configurations. By explicitly defining urban configuration, it demonstrates how the spatial arrangement of high-rise and low-rise environments affect wayfinding behavior. The emphasis on building height and spatial complexity contributes to a deeper understanding of urban morphology, building on prior findings that link urban density, vertical elements, and environmental legibility (Brunyé et al. 2010; Hölscher et al. 2011). These findings reinforce the significance of three-dimensional urban form in shaping navigation and spatial cognition, consistent with Lynch's (1960) principles of urban imageability. The video game-based VR methodology provided a viable alternative to traditional and modern wayfinding studies. Using this method, the study discovered associations between urban configuration, the perception of city image elements, as well as urban design qualities of street environments.

Furthermore, the study explored the impact of urban configuration on wayfinding behavior. The results reveal significant differences in wayfinding performance across different urban configurations, pointing to the importance of environmental structure in the development of spatial knowledge. These findings are supported by Credé et al. (2020), who show that individual differences in spatial learning are strongly influenced by the visibility of landmarks. Their research suggests that certain users, depending on their cognitive abilities and prior experience with navigation, may perform better in environments where landmarks are easily identifiable and visible from a distance. This aligns with our observations that performance varied among participants, suggesting that individual cognitive profiles may explain differences in navigating through high-rise versus low-rise environments. These findings underscore the need to consider individual user characteristics when designing urban spaces to improve navigational ease and suggest that future research should further explore how personal differences in spatial cognition affect interactions with complex urban layouts.

In addressing the first research question, "Is there a difference in wayfinding performance according to urban configuration?", the findings show that wayfinding performance does indeed vary across different urban configurations. The questionnaire survey revealed a clear ascendancy in the importance attributed to wayfinding factors from low-rise to high-rise configurations. For instance, participants rated legibility highest in the high-rise setting, which suggests that this configuration facilitated a better understanding of the environment. This aligns with Dogu and Erkip (2000), who provided evidence that legibility increases when users can comprehend the environment and its design. Moreover, factors such as landmarks, enclosure, complexity, and transparency were rated lowest in the low-rise environment and highest in the high-rise environment. While the increase is not perfectly linear, the general trend indicates that these factors played a more significant role in wayfinding within high-rise settings. The difference between unguided route following (second wayfinding time) and guided route learning (first wayfinding time) was especially notable in the high-rise environment, where the average time to complete the wayfinding task was significantly shorter for most participants. This reduced time suggests more efficient navigation, demonstrating improved route knowledge in high-rise settings and further supporting the conclusion that certain urban configurations enhance participants' perception of relevant wayfinding factors. O'Neill (1991) proposed that the physical environment affects mental images formed during wayfinding, which in turn affects actual performance and decision making. This study expands on this by showing how specific urban configurations directly affect wayfinding performance. In conclusion, the high-rise environment contributes to a heightened level of perception, supporting the idea that cognitive images are better developed in these areas.

The second research question asks, "Is there a difference in wayfinding propensity according to urban configuration?" was addressed by investigating participants' wayfinding behavior when given multiple route options to return to a destination. The analysis revealed that urban configuration significantly influenced participants' route choices during the second wayfinding task. Specifically, participants in high-rise settings demonstrated an improved ability to identify alternative, simpler routes, possibly due to the development of more comprehensive cognitive images during the first task. This finding is corroborated by the observation that total wayfinding time for each participant was lowest in high-rise areas, consistent with previous research linking abstract environmental qualities such as complexity and human wayfinding behavior (Li and Klippel 2012). Credé's (2018, 2020) work further supports this conclusion by asserting that the influence of global landmarks are especially pronounced in high-rise environments. Together, these findings indicate that high-rise configurations facilitate better spatial learning and adaptability in navigation tasks. The analysis of absolute second wayfinding times further supports these findings, with Vinewood achieving the fastest performance (454.3 s), followed by Pillbox Hill (523.7 s), and Little Seoul (651.4 s, Table 2). Regression analysis confirmed that legibility, human scale, and enclosure significantly reduced,



with Pillbox Hill participants navigating faster than those in Little Seoul (Table 5). These results underscore the high-rise environment's role in enhancing navigational efficiency through improved spatial learning, driven by distinct urban design qualities and route adaptability.

Regarding enhancements in participants' performance, while prior research indicates that repeated exposure can improve proficiency (Lin et al. 2019), this study suggests that these improvements are more pronounced in high-rise settings due to the concept of imageability within these environments. Imageability can be regarded as a cumulative effect of several urban design trait such as legibility, enclosure, human scale, transparency, linkage, complexity, and coherence, many of which were rated higher in high-rise settings. Landmarks, as identified by Lynch (1960), play a key role in enhancing imageability; however, they are not limited to prominent structures. Instead, they can include any element possessing distinct qualities within its context. Validating this perspective, our data revealed that perceptions of landmark significance were most pronounced in Pillbox Hill, a notable area within the high-rise environment. This suggests that the architectural and spatial features of high-rise zones inherently create a more vivid cognitive impression on observers. These findings offer valuable insights for designing urban areas, particularly in places frequented by both local and foreign tourists. Urban spaces should facilitate intuitive wayfinding to minimize stress (Edwards and Griffin 2013). Furthermore, Lynch (1960) argued that a clear sense of one's urban environment is closely tied to self-identity and a sense of belonging within society. Environments that support easier wayfinding not only improves comfort but also enhance memory retention, ultimately fostering a stronger connection to the space. The robust association observed between urban configuration and wayfinding performance highlights the importance of environmental structuring in improving navigation. However, Credé et al.'s study introduces an important nuance by showing that individual differences, such as spatial abilities and familiarity with navigation tasks, significantly mediate the effectiveness landmark in spatial learning. This suggests that while high-rise environments generally lead to better navigational outcomes due to distinct landmarks, the benefits can vary widely depending on the individual. Such variability may impact generalizability of these findings across different populations; therefore, urban designs considering varying cognitive abilities may be more effective in supporting successful wayfinding. Integrating these insights into urban planning could lead to inclusive designs that accommodate diverse navigational proficiencies. This aligns with our conclusions about how physical configurations shape wayfinding behaviors and suggests a layered approach to urban that considers both structural impacts and individual user differences. While the extent to which geographic and demographic factors moderate these effects remains uncertain, cultural differences being one factor, it is clear that all individuals are influenced by configurational cues in their surroundings.

By evaluating urban image elements such as paths, nodes, edges, districts, and landmarks, this study leans on Ewing and Handy's (2009) foundational framework. While their methodology is widely recognized, it is semi-objective, relying on expert ratings. This study slightly diverges by incorporating assessments from graduate students specializing in urban design, while remaining anchored to Ewing and Handy's original formula. It is important to note awareness of the authors of the limited R-squared (R^2) values associated with Ewing and Handy's model, which these indicate moderate explained variance by their predictors and suggest other influential factors may exist unconsidered. Additionally, we recognize differentiated R^2 values inherent across dimensions like imageability or legibility as outlined by their work but gravitate towards their approach due to its pioneering insights into walkability.

While we recognize the limitations of the framework used in this study, its enduring relevance strengthens our decision to incorporate it, as it remains contextually relevant today, despite emergence of newer methodologies post-Ewing and Handy's inception. A potential limitation to consider is the homogenous nature of the sample, which comprised solely of participants from a single Korean ethnicity. This limits the generalizability of our findings to diverse ethnic groups, suggesting that future studies should systematically investigate our findings across diverse participant backgrounds. In critically evaluating how urban environments affects wayfinding performance, it is necessary to revisit Kevin Lynch's theories proposed in "The Image of the City" (1960). His work serves as a foundational cornerstone in urban design, and our findings further substantiate his theory, highlighting environmental elements enhancing performance through bolstering legibility. However, the application of Lynch's framework in contemporary urban environments requires a critical reassessment as evolving landscapes introduce complexities he may not have fully considered since his era. High-rise configurations being one example where cognitive images extend beyond reliance solely on distinct physical landmarks but influenced collectively through various design qualities augmenting imageability. Moreover, Lynch's viewpoint may be reassessed based on potential oversimplification regarding human cognitive mapping processes within complex urban settings. The intricate interrelationships between perceptive qualities engender nuanced cognitive images that go beyond his foundational ideas. Therefore, it must be adapted and expanded to accommodate the evolving complexity of contemporary urban spaces.

While this study provides valuable insights into factors influencing wayfinding propensity, it acknowledges several



methodological limitations. First, the use of video game-based environments, though pragmatic, lacks the immersive fidelity of modern VR systems or observational methods, which are better equipped to capture the dynamic, multisensory influences of navigation, such as soundscapes, pedestrian movement, and nuanced visual details. Additionally, the prebuilt landscapes GTA V may not represent the diversity of real-world configurations across various contexts; future studies could integrate immersive VR hybrid methods combining computer vision street-view imagery addressing constraints effectively. Moreover, this approach does not incorporate objective measures of design qualities, such as green view or sky view indices, which recent studies have shown to be effective in evaluating urban spaces and enhancing the understanding of dynamics influencing navigational experiences within complex environments. This warrants consideration for future inquiries into comprehensive assessments encompassing multifaceted aspects impacting user interactions spaces designed to facilitate intuitive movement exploration, which ultimately enriches overall engagement quality within contemporary urban landscapes.

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Data availability The date sets generated and analyzed during the study are availble from the corresponding author upon reasonable request.

Declarations

Ethical approval The study was approved by the Research Ethics Committee of Chung-Ang University, Seoul, Korea.

Informed consent All participants were informed about the purposes of the study and gave their written consent in accordance with the university guidelines.

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