Article:

Lu, X., Tomkins, A., Hehl-Lange, S. et al. (1 more author) (2021) Finding the difference : measuring spatial perception of planning phases of high-rise urban developments in virtual reality. Computers, Environment and Urban Systems, 90. 101685. ISSN 0198-9715

https://doi.org/10.1016/j.compenvurbsys.2021.101685

Computers, Environment and Urban Systems 90 (2021) 101685

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Finding the difference: Measuring spatial perception of planning phases of high-rise urban developments in Virtual Reality

Xi Lu *, Adam Tomkins, Sigrid Hehl-Lange, Eckart Lange

Department of Landscape Architecture, University of Sheffield, UK

ARTICLE INFO

Keywords:
Gaze tracking
Virtual reality
Spatial perception
Planning phase
High-rise
Pearl River Delta

ABSTRACT

Planning is a process in which the contents of planning is gradually refined. However, research in planning communication and perception is often conducted using contrasting scenarios, e.g. by comparing a with/without case. It is not surprising that drastic differences in planning content and representation result in significant differences in perception. Instead, and as a reflection of sequential and gradually evolving projects in planning practice, we are focusing on two planning phases with only subtle differences (2015 and 2018) for a new high-rise development district in Guangzhou. We introduce 3D gaze-tracking and spatial perception experiments to investigate how participants respond to virtual representations of the two planning phases. The results provide implications for planning and design practice and suggest more substantial roles for the general public in participatory planning processes.

1. Introduction

Urban planning is a continuous process of forecasting, planning, and managing change and development (Adams, 1994). With stakeholders providing input and feedback at key phases of the planning process, an urban planning project usually develops from a conception in broad terms towards a more precise design and implementation (Amado, Santos, Moura, & Silva, 2010; Taylor, 1998; Watson, 2003). In the early phase, the main focus is on the delimitation of boundaries and land use. Regulatory indices, such as the height and bulk of buildings, are then applied. The actual design develops and changes over time but often with somewhat coherent physical forms adopted in the later stage (Bacon, 1967). As the plan becomes more detailed and complex, it can be deconstructed into a series of future actions before decision-making and implementation (Hopkins, 2001; Watson, 2003).

Although the planning process usually develops gradually over time, it may sometimes be interrupted by internal and external environmental factors, leading to a directional change (Hersperger et al., 2018; Masser, 1983). To cope with this uncertainty and complexity, increasing importance has been placed on the use of scenario planning as a strategy for responding to divergent demands and viewpoints of stakeholders (Amer, Daim, & Jetter, 2013; Xiang & Clarke, 2003). In a participatory scenario planning process, the situation at a given point in time is often compared with multiple scenarios that might happen in the future, and that are in parallel, typically expressed by contrasting either content or forms of presentation (Sheppard, 2015; Steinitz et al., 2003).

Various visualisation techniques have been used to facilitate the communication of future visions and to examine related impacts (Bishop, 2015; Kim & Newman, 2020; Lewis, 2012; Pettit, Raymond, Bryan, & Lewis, 2011). For example, Dockerty et al. (2005, 2006) examined how stakeholders respond to different land-use scenarios influenced by climate change and local policy using landscape rendering software (VNS). Lange, Hehl-Lange, and Brewer (2008) generated four 3D scenarios – “Agriculture”, “Recreation”, “Nature conservation” and “Wind turbines” – for comparison with the status quo for a green space development in Switzerland. Han and Peng (2019) compared highly contrasting scenarios regarding coastal flooding management of Miami-Dade County through agent-based modelling. Not surprisingly, significant differences in scenario contents and means of representation, can lead to significant differences in public perceptions.

The body of work that links planning scenarios to visualisation and perception has primarily focused on alternative futures side-by-side, rather than scenarios that develop over time. As pointed out by Lange and Hehl-Lange (2010), visualisation techniques can be used to show more than the final vision of planning. This point is also emphasised by Sheppard et al. (2011, p. 409), who write that images of planning

* Corresponding author at: Department of Landscape Architecture, Arts Tower, Western Bank, Sheffield S10 2TN, UK.
E-mail addresses: luxi.cn@outlook.com (X. Lu), a.tomkins@sheffield.ac.uk (A. Tomkins), s.hehl-lange@sheffield.ac.uk (S. Hehl-Lange), e.lange@sheffield.ac.uk (E. Lange).

https://doi.org/10.1016/j.compenvurbsys.2021.101685
Received 23 January 2021; Received in revised form 14 May 2021; Accepted 5 July 2021
Available online 19 August 2021

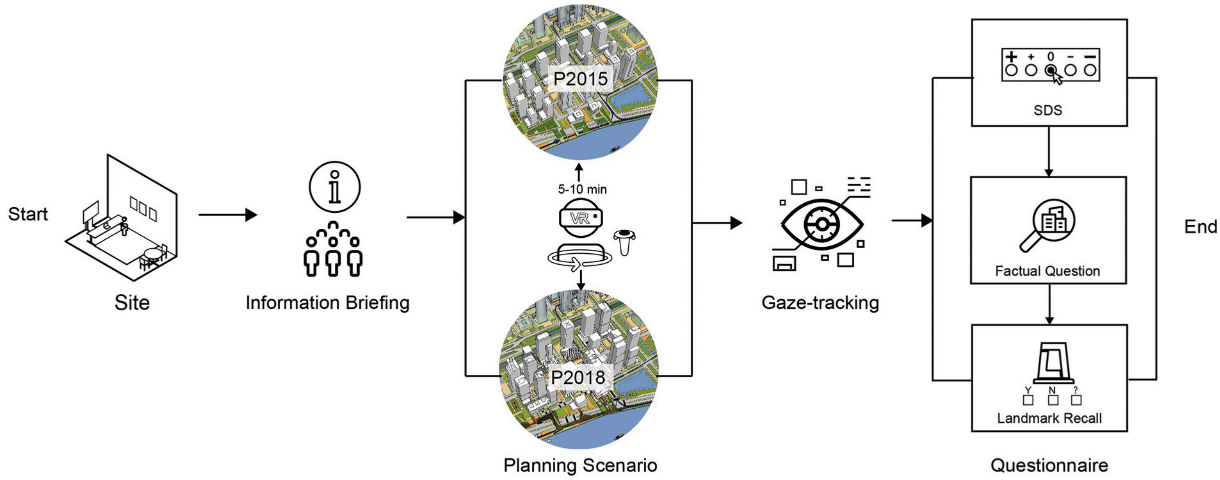


Fig. 1. Overview of the experimental process.

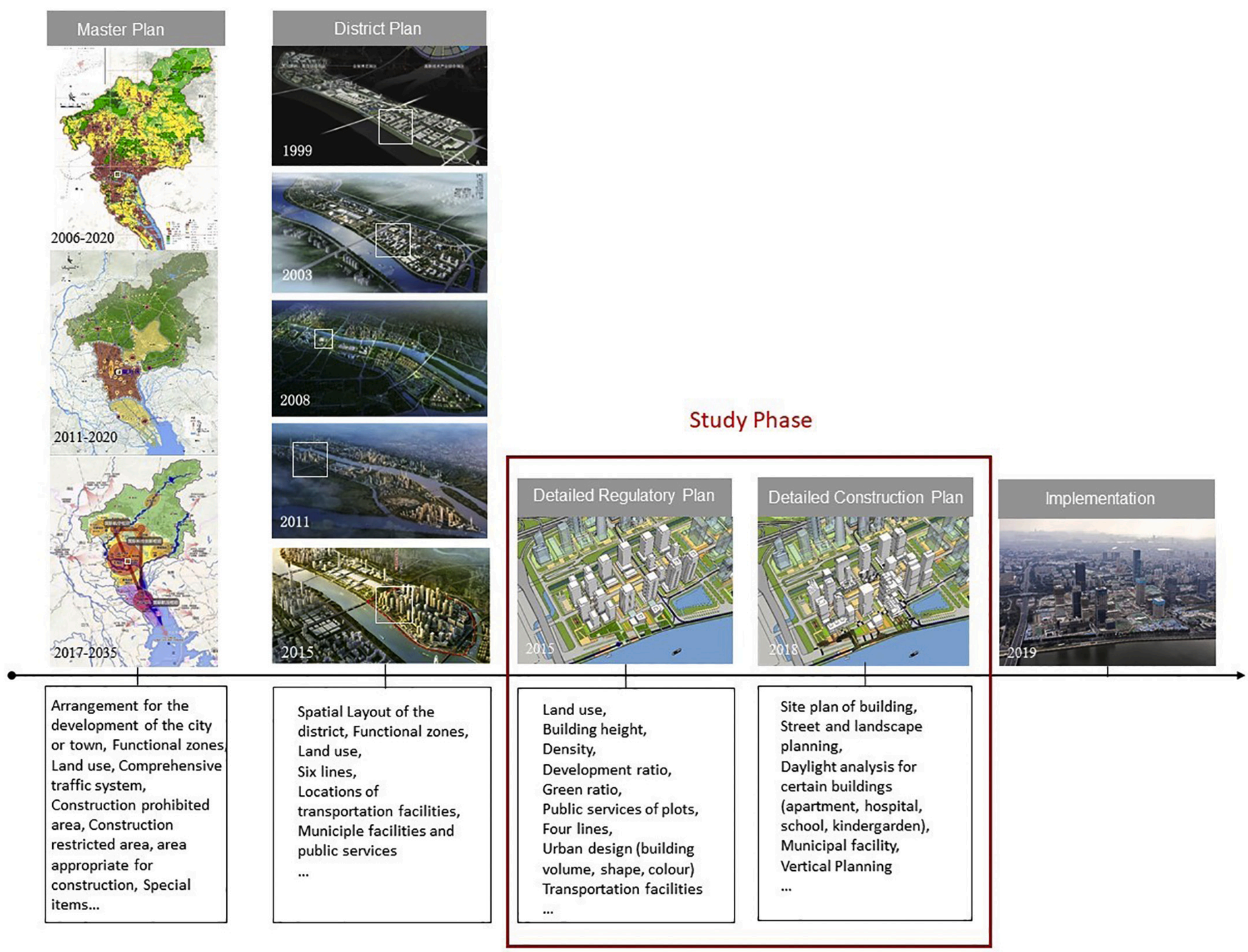
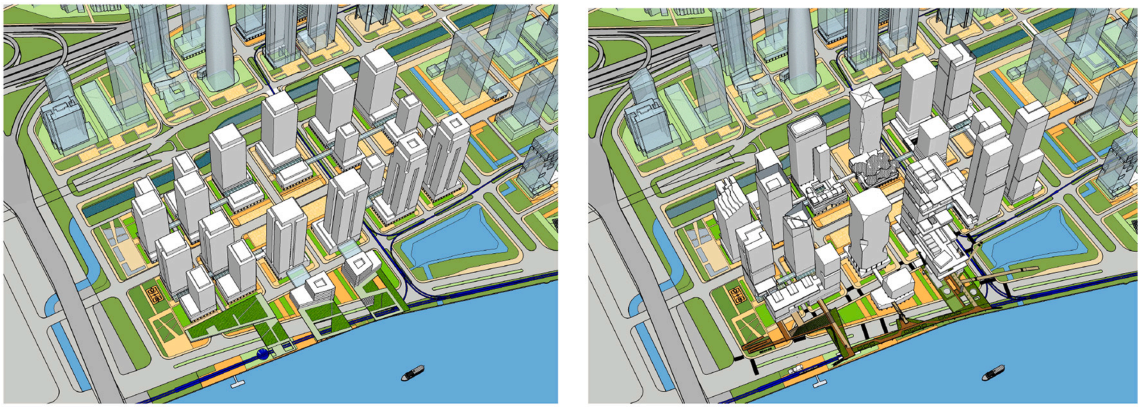


Fig. 2. The statutory development process of PIIC, Guangzhou, China, moves from master plan to district and detailed plan (including detailed regulatory plan and detailed construction plan). Requirements for each process develop from broader conceptions to detailed architectural refinements. This study focuses on the latter two phases, in 2015 and 2018, respectively.
Image source: Guangzhou Natural and Urban Resources Bureau; Yimin Sun Studio, South China University of Technology, Guangzhou.



(a) (b)

Fig. 3. Two phases of urban planning at (a) P2015, (b) P2018; Buildings in white belong to the study site, and buildings that are transparent illustrate the surrounding environment.
Source: Yimin Sun Studio, South China University of Technology, Guangzhou.

scenarios are neither the beginning nor the end, but the middle of the process. By illustrating a sequence of time that includes intermediate steps, visualisation provides a way of showing the changes in planning in the search for optimised planning solutions in the long term (Lange & Hehl-Lange, 2010; Ramos, 2010).

Dramatically different scenarios as used in the early phases in planning, are less likely to be incorporated towards the later phases in real-world planning practice. The closer the project is to its completion, the less likely is sudden change and the focus will be on fine-tuning (Bacon, 1967). One reason for this is that a certain path has usually been determined by earlier stakeholder negotiations, which may have incurred high transition costs (Luccarelli & Røe, 2016). There may also be limited time and budget allowed for project completion. E.g. in the High Speed 2 (HS2) project in the UK, after analytical, consultation and appeal processes took place, several alternative routes were proposed. Once the definite route was decided further phases of design development would then produce detailed and concrete refinements (stations, junctions, corridors, etc.) (GOVUK, 2018).

Gradual and sequential developments in planning, and the ways people perceive or react to them, have not yet been studied in detail. Where planning alternatives with subtle differences are presented, studying public perceptions are not the main focus of the research (Roupé, Bosch-Sijtsema, & Johansson, 2014; Roupé & Gustafsson, 2013). For instance, Roupé et al. (2014) presented various building scenarios in an investigation of user experience of two types of VR interface. Elsewhere, although planning alternatives were shown in a

(a)

Fig. 4. (a) A pre-determined route with 30 stops in the 3D virtual environment; (b) Selective scenes at different waypoints on a participant's journey in P2018.

Fig. 4. (*continued*).

sequential series (Bishop, Pettit, Sheth, & Sharma, 2013; Lange & Hehl-Lange, 2010; Sheppard et al., 2011), the contents of the scenarios differed significantly.

Therefore, in this paper, instead of using contrasting scenarios and in accordance with gradually evolving planning projects in practice, we are focusing on a brief sequence comprising of two planning phases (2015 and 2018) of a new high-rise development district in Guangzhou, the Pazhou Internet Innovation Cluster (PIIC). Using the latest developments in gaze tracking techniques allows us to measure an individual's visual attention, and through conducting perception experiments the aim of this research is to explore whether and how participants respond to virtual representations of marginally different planning phases as part of a longitudinal planning process.

2. Methodology

2.1. Overview

The experiment was conducted as part of the Pop-up University, a three-day public event, held from September 20th-22nd 2019 at Millennium Gallery, Sheffield, UK. The Millennium Gallery is one of the city's most popular and iconic venues, attracting a large number of visits. It provides a setting for active public engagement, reducing the volunteer bias which may occur through self-selection recruitment in laboratory settings (Salkind, 2010). The experiment was approved by the ethics committee of the Department and followed five steps as shown in Fig. 1. First, visitors who showed an interest in engaging with the VR exhibition were recruited. They were then informed, both orally and in written format, about the context of the project and asked to sign the consent form. Randomly and in turns, they were allocated to one of the two planning phases, ensuring each phase had an adequate number of participants. Then, they were introduced to a Mixed Reality head-mounted device and its operation through which they could navigate following a predesigned route in the virtual environment (VE). Viewing patterns of participants were recorded through automated 3D gaze-tracking. Finally, questionnaires were distributed to participants in order to examine their spatial perception of the virtual environment, including exploring attitudes towards the VR device and urban design using a semantic differential scale (SDS), checking factual variables and testing recognition of buildings that had been shown in the experiment.

2.2. Case study site and simulation

The case study site, comprising an area of 0.415 km^2 and a plot ratio of 9.4 in Guangzhou, China, is a proposed e-commerce cluster for leading Chinese Internet and Hi-Tech giants such as Alibaba, Tencent, Guomei and Xiaomi. The statutory development process of the area is shown in Fig. 2. After two decades of adjustments to the land use in higher level plans, Phase 2015 (P2015) focuses on regulatory indices of the proposed development (Fig. 3a). Following on, the focus in Phase 2018 (P2018) is on architectural design, as influenced by the different land owners and international architecture and design teams (Fig. 3b). As a result, some buildings are slightly different or complex, and the number of buildings also varies slightly between the two planning phases. The overall setting of the road network and surrounding environments remain unchanged.

Fig. 5. Data interpreting process of gaze tracking data.

A pre-determined route with a length of 2671 m (see Fig. 4a) ensures that participants are equally exposed to the proposed development and fully explore the design. Building on the “serial vision” concept to represent human-environment interaction during a walkthrough in urban settings (Cullen, 1961), we introduce a leap function with 30 stops across the route in the virtual environments (VEs). Two sample videos showing participants’ explorations of the immersive visualisation of P2015 and P2018 are included in the supplemental material. Fig. 4b displays selective scenes at different waypoints in the participant’s journey. After an information briefing at Waypoint 0, it starts with a waterfront view (Waypoint 1–7) and moves to a boulevard promenade between buildings at Waypoint 8–12. Waypoint 13–28 displays scenes alongside or between the buildings. A pop-up notice in the final waypoint marks the end of the exploration.

2.3. Eye-gaze tracking and data processing

The terms *eye tracking*, *gaze tracking*, or *eye-gaze tracking* are often interchangeably used in tracking related studies. Eye-tracking detects and records the gaze points in tandem with the eye movements of users, which could be later aggregated to form fixations (the gaze position held for a long time) and saccades (the movement of the gaze from one place to another) (Blascheck et al., 2014). Instead of tracking individual eye movements, gaze tracking (point of regard) is the analysis of eye tracking data in relation to head or visual scene (Chennamma & Yuan, 2013). We use the term *eye-gaze tracking* to refer to the synthesis of both studies.

Eye-gaze tracking studies in planning have been conducted in both virtual and real environments, using either immersive headsets or relatively remote devices such as desktop facilities and 3D CAVE (Simpson, Freeth, Simpson, & Thwaites, 2019). Studies employing head-mounted devices in VEs have well elucidated how the public perceive two-dimensional (2D) static images. For instance, Pihel, Ode Sang, Hagerhall, and Nyström (2015) compared the influences of planning expertise in eye movements when assessing the biodiversity of a forest landscape. Dupont, Ooms, Antrop, and Van Eetvelde (2016) examined how people viewed and perceived photographs of real-world landscapes through salience maps and eye-tracking metrics. Noland, Weiner, Gao, Cook, and Nelessen (2017) conducted a visual preference survey of how individuals process and rank images used in public settings of urban planning.

One limitation of these studies is that the visual patterns in the static VEs only show the relative positions of the user’s eyes in relation to his/her head, whereas the 3D positions of the user’s eyes in the real scene remain undetected (Shih & Liu, 2004). Dorr, Martinetz, Gegenfurtner, and Barth (2010) and Danahy (2001) have also argued that the framing of static stimuli could narrow the field of vision and therefore produce less natural viewing patterns. To acquire participants with more dynamic experience, some recent attempts have used 3D VEs. Amati, Parmehr, McCarthy, and Sita (2018) tracked participants while viewing videos of walks in urban parklands in Melbourne. Zhang, Zhang, Jeng, and Zeng (2019) captured participants’ 3D point cloud visual data through a virtual walkthrough in a Chinese historical street. Nonetheless, the visual stimuli in these studies are limited to small-scale low-rise environments as a result of technical difficulty and complicated data interpretation.

Building on Tomkins, Hehl-Lange, and Lange (2019), we introduce a 3D gaze-tracking approach to understand the salient perspectives unveiled during navigation of a complex high-rise environment.

The virtual model of the research area was imported from the FBX format of sketch-up models into the Unity Games Package. A Lenovo Explorer Windows Mixed Reality Headset was employed to allow for immersive travelling experience. Through regular recordings of the position and progress of viewports and focal points in a 3D virtual space, participants’ perspectives during their virtual exploration could be reconstructed and depicted. Each participant was assigned a unique number. The following metrics were recorded during their virtual exploration:

1) the overall time spent exploring the 3D model from each vantage point;
2) the overall time spent focusing on each point in the 3D model;
3) the unique times of view for each vantage point and focal point.

The data was aggregated and processed by compressing continuous participant trajectories into a discrete “voxel” 3D grid system (see Fig. 5). We were then able to reconstruct the participants’ spatial experience and organize the range of visual patterns to extract maps, such as the unique numbers of view per waypoint, voxel positions per waypoint, time of duration per waypoint. This data could be further broken down to interpret the differences between different subgroups towards the two planning phases.

2.4. Survey and data analysis

Combining subjective perception and objective analysis facilitates a

Table 1
Demographic components of effective participants.

Demographic factors		P2015	P2018	Total
		N (Percentage)	N (Percentage)	N (Percentage)
Total		42 (100%)	45 (100%)	87 (100%)
Age	18–44	35 (83%)	39 (87%)	74 (85%)
	45+	7 (17%)	6 (13%)	13 (15%)
Gender	Female	23 (55%)	25 (56%)	48 (55%)
	Male	19 (45%)	20 (44%)	39 (45%)
Education level	No university degree	6 (14%)	6 (13%)	12 (14%)
	University degree (BA, BSc)	13 (31%)	14 (31%)	27 (31%)
	Higher degree (MA, PhD, PGCE)	23 (55%)	25 (56%)	48 (55%)
Lay or professional	Professional	12 (29%)	13 (29%)	25 (29%)
	Laypeople	30 (71%)	32 (71%)	62 (71%)
VR experience	Yes	19 (45%)	21 (47%)	40 (46%)
	No	23 (55%)	24 (53%)	47(54%)

better understanding of the spatial experience (Makransky, Terkildsen, & Mayer, 2019). A frequently used self-assessment tool for gauging opinions is the semantic differential scale (SDS), which asks participants to provide their attitudes of the proposed environment through bipolar adjectives on a given scale (Osgood, 1964). For objective measurements of spatial knowledge acquisition, landmark, route, and survey knowledge are frequently used indices (Cubukcu & Nasar, 2005). Landmark knowledge tests whether a participant is able to determine if a particular object exists in the presented environment. Route knowledge is related to sequential learning and actions along the route. Survey knowledge concerns the spatial layout, places, landmarks and their interrelationship.

Building on experiments that explored human-environment interaction (Kuliga, Thrash, Dalton, & Hölscher, 2015; Omer & Goldblatt, 2007; Willis, Hölscher, Wilbertz, & Li, 2009), and urban design principles (Banerjee & Loukaitou-Sideris, 2011; Watson, 2003), we examined participants' attitudes to the two planning phases, asked factual questions and tested landmark recall about the presented virtual environment. The questionnaire includes four parts:

1) Participants' socio-demographic information, including age, gender, level of education, planning expertise and prior VR experience.
2) A five-point semantic differential scale (SDS) to assess participants' attitudes towards the VR device and urban design, incorporating seven pairs of adjectives:
   VR device; "helpful for understanding - not helpful for understanding", "easy to use - hard to use", and "realistic - abstract".
   Urban design; "detailed - simple", "interesting - boring", "beautiful - ugly", and "unique - repetitive".
3) Three factual tests, including estimation of the height of the tallest building (200 m) in the VE, the number of buildings (For P2015, $N = 19$; P2018, $N = 14$), and the distance travelled following the predefined route (2671 m).
4) One landmark recall test. A scorecard was shown to the participant which contains the actual building blocks and other buildings that don't exist in the VE (For P2015, 19 existing +11 non-existing; P2018, 14 existing +11 non-existing). Participants were asked to tick the images of building blocks that they either think existed/did not exist in the VE or whether they were uncertain.

The distance/height estimations were determined based on the discrepancies between participants' answers and the actual data (Difference = Estimation – Reality) (Paes, Arantes, & Irizarry, 2017). The Difference of "Estimation – Reality" for height is "Estimation – 200", and for distance "Estimation – 2671". Due to the disparity between the building blocks in each planning phase (P2015 = 19, P2018 = 14), the sampling size bias for estimation of building numbers was balanced using the disparity rate [D = (Estimation – Reality)/Reality * 100%]. Theoretically, the smaller the absolute results of the "Estimation – Reality" discrepancy and the disparity rate, the more accurate the results. Landmark recall tests were measured by the sum scores of participants' answer sheets with corresponding scores balancing the accurate rate assigned to one of the three categories: correct (P2015 = 1, P2018 = 1.13), unsure (P2015 = 0, P2018 = 0) and wrong answers (P2015 = −1, P2018 = −0.83). In response to the differences in full marks for each phase (30 for P2015, 28.25 for P2018), participants' test results in P2018 were scaled to a total value of 30 to compare with P2015.

Data analysis was conducted through IBM SPSS version 25.0. The demographic data was examined through descriptive statistics. The internal consistency reliability of the SDS was examined by Cronbach's α coefficient, see, e.g. Kang and Zhang (2010) and Field (2013). The mean values of the SDS were compared using scatter plots with scores ranging from 1 to 5. The normality distribution of the SDS and spatial knowledge test results were then examined through the Kolmogorov-Smirnov test (Ghasemi & Zahediasl, 2012). Except for the landmark recall results, data from the tests were not normally distributed. Participants' overall perceptions of the two planning phases were first analysed using the Mann-Whitney test for the SDS and three factual tests, and an independent-samples *t*-test was conducted to assess the landmark recall results.

To understand the variation in perceptions per personal demographic component, within-phase and between-phase comparisons were conducted using suitable non-parametric (Mann-Whitney *U* tests and Kruskal-Wallis tests) and parametric tests (one-way ANOVA) by different demographic subgroups (Field, 2013). Pairwise comparisons were carried out to confirm where significant differences occurred.

3. Results

Altogether 87 participants were successfully involved. Although there were more participants overall, because of research ethics requirements children had to be excluded, as well as participants with abnormal vision or incomplete experiments. The demographic components of participants are listed in Table 1. As different age groups are unevenly distributed (which decreases statistical power), we primarily focus on the perceived differences between gender, education level, planning expertise and prior VR experience in the two planning phases.

3.1. 3D gaze-tracking indicating when, where and for how long people have looked at the virtual environment

The voxel positions, voxel numbers and viewing time at each waypoint were plotted to illustrate participants' gaze behaviours across the different phases. Fig. 6a and b show the overall exploration patterns of the models in the 3D coordination system. The plan view of P2018 shows a slightly more concentrated pattern compared with P2015. Fig. 7 represents that the height distributions of voxel positions in both phases

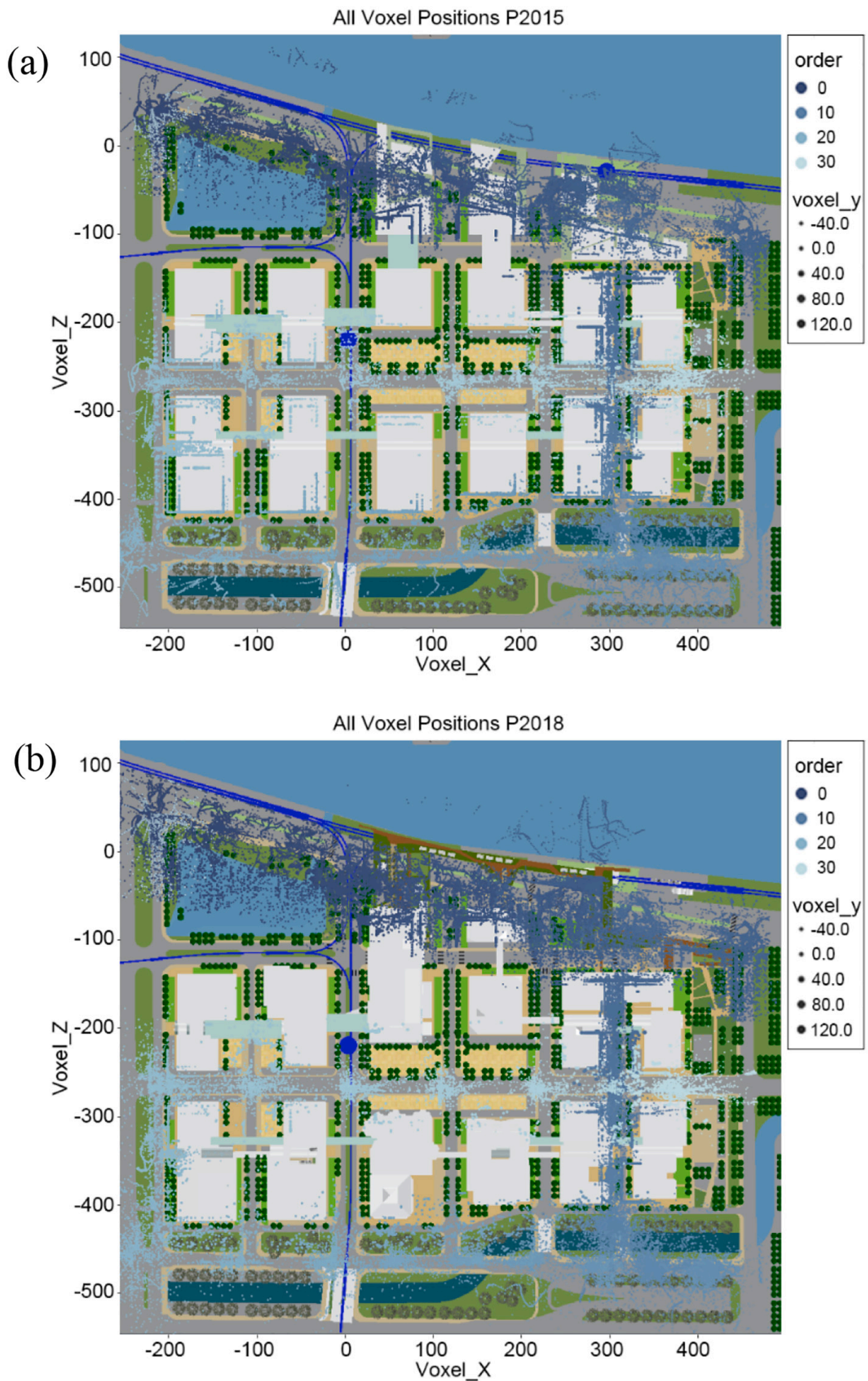


Fig. 6. Plan view of voxel positions in (a) P 2015, and (b) P 2018.

range from 0 to 80 m in the VEs. Participants most frequently looked at heights of up to 5 m, and their visual attention decreases as the height increases.

Fig. 8a and b demonstrate the participants' viewing time and voxel numbers at each waypoint in the two planning phases. Both metrics fluctuated in the earlier stage of the journey, with turning points occurring at Waypoint 3, 5, 8, 9 and 12. Subsequently, they remained low and steady until they began rebounding at the end. Overall, P2018 attracted more voxel counts and longer engagement time than P2015. Between the two phases, some significant differences were revealed in the initial part of the journey. At Waypoints 3 and 4, P2015 attracted a longer exploration time while the voxel counts were similar between the two phases. Despite the comparable time spent viewing at Waypoints 4–7, P2018 attracted more attention than P2015. At waypoints 9, 10 and 11, however, the extent of exploration did not change significantly over time; it actually decreased slightly. Nonetheless, at these points, the P2018 model attracted lengthier viewing time compared to P2015.

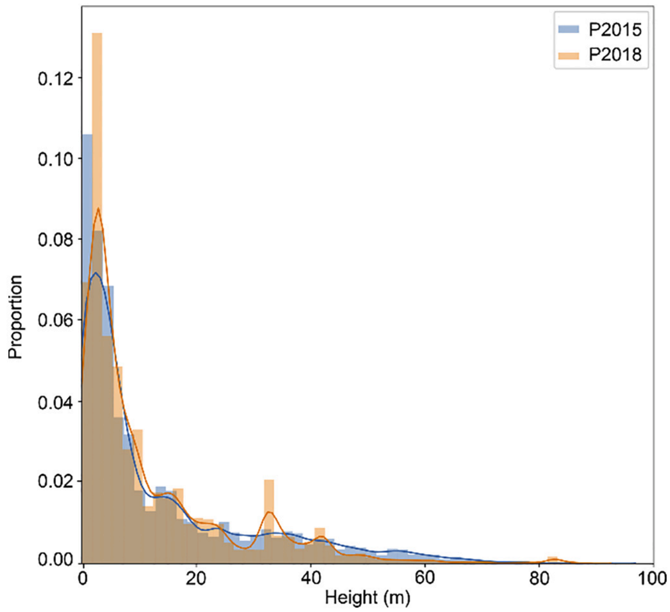


Fig. 7. Height viewing distributions in P2015 and P2018.

3.2. *Spatial perception unveiled through semantic differential scale and knowledge tests*

Participants' SDS evaluation had a good internal consistency (α = 0.822). Overall, no significant differences were detected in SDS results between the two phases. They showed positive attitudes towards the VR device and urban design (Fig. 9). In both phases, the VR device was perceived as generally helpful for understanding, easy to use and realistic. Regarding the urban design, such as detail, beauty and uniqueness, P2018 was marginally preferred over P2015.

Gender, planning expertise, and education level were not influential factors for participant's perception within and between different phases (see Appendix A for detailed statistical results). Prior VR experience did however play a role. Within P2015, participants without VR experience ($M = 4.83$, $SD = 0.39$) considered the device more helpful for understanding than the experienced user ($M = 4.47$, $SD = 0.51$) ($U = 141.5$, $p = 0.017$). Within P2018, the environment was perceived to be less realistic by the experienced group ($M = 3.48$, $SD = 1.08$) than the first-time user group ($M = 4.13$, $SD = 0.85$) ($U = 235.5$, $p = 0.037$).

The experimental tests as shown in Table 2 show no significant differences between participants in estimating regulatory parameters for both phases, such as height, number, and distance. Estimates were slightly better for P2018 than for P2015. Overall, the height of the tallest buildings in the virtual environment was judged to be considerably lower than their actual height. Similarly, the estimated building numbers were slightly lower than the actual number of buildings. The median of participants' judgements of the distance travelled in the VEs was much shorter than the real routes. Significant differences were found between the two phases in relation to landmark recall: $t\ (84) = -2.156$, $p = 0.034$. Planning at P2018 ($M = 4.82$, $SD = 4.26$) showed a significantly better result than at P2015 ($M = 2.12$, $SD = 7.09$).

When comparing between- and within-phase variances, all demographic subgroups (gender, education level, planning expertise, VR experience) did not reach statistically significant differences in relation to regulatory indices (height, number and distance). In terms of landmark recall tests, no significant differences were found in factors including gender, planning expertise, and prior VR experience; however, education level is a significant factor on landmark recall tests between/within the phases (see Appendix B for detailed statistical results).

As shown in Fig. 10, participants with higher education degrees demonstrated significantly better scores in P2018 ($M = 5.53$, $SD = 3.6$) than those engaged in P2015 ($M = 1.52$, $SD = 6.44$), $t\ (34.193) = -2.626$, $p = 0.013$. Within P2018, there was a statistically significant difference between groups with various education levels as shown by one-way ANOVA ($F\ (2, 41) = 4.043$, $p = 0.025$). Post hoc comparisons using the Tukey's test shows that, in P2018, participants without a university degree ($M = 7.72$, $SD = 4.53$) scored significantly higher in the landmark recall tests than those with a university degree ($M = 2.52$, $SD = 4.40$) ($p = 0.043$).

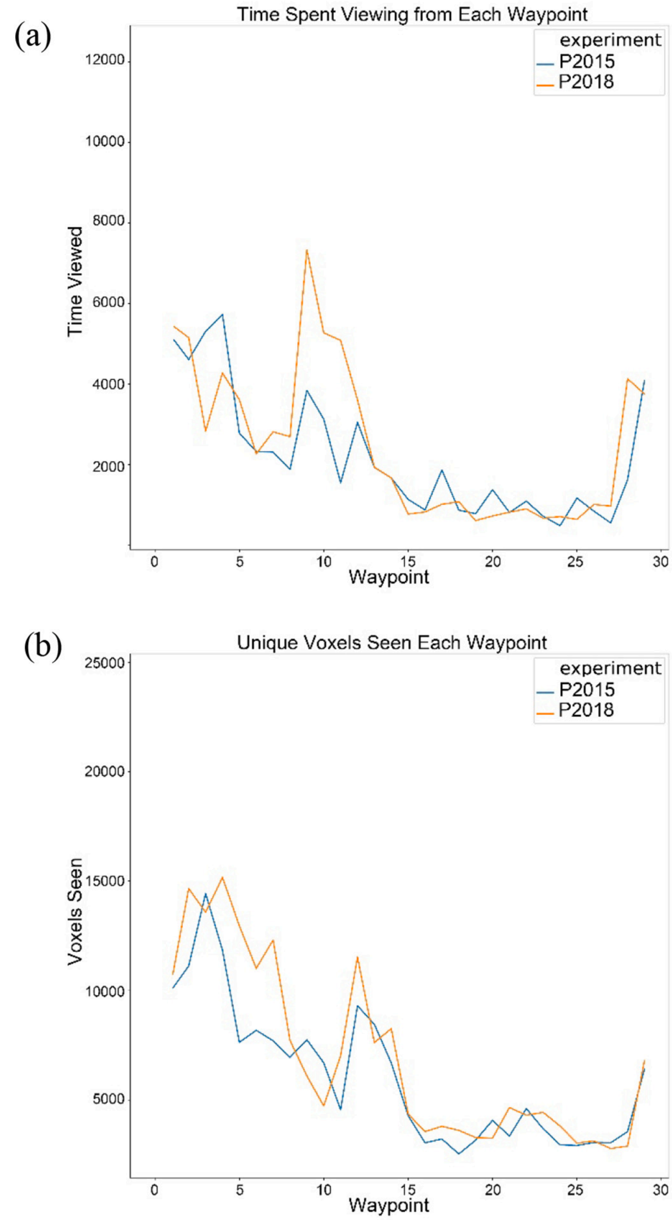


Fig. 8. Visual exploration from each waypoint (a) time spent viewing, (b) unique voxels.
Note: data in Waypoint 0 is removed due to the time spent adjusting to the VEs and reading the information briefing.

4. Discussion

4.1. *Interpreting the visual engagement in the 3D high-rise environment*

3D gaze-tracking provides an objective and automated approach to understand human visual dynamics during movement in the urban environment compared to conventional studies that rely on observation

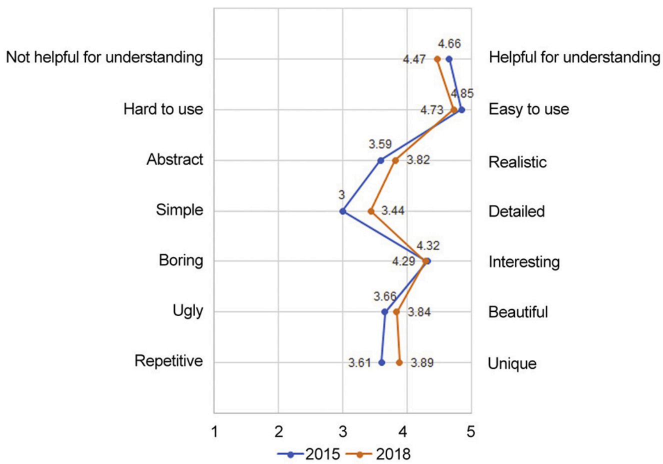


Fig. 9. Semantic differential scales of the two planning phases.

and mapping techniques, such as those in Cullen (1961), Appleyard, Lynch, and Myer (1964), and Bacon (1967). High fixation counts are often linked with increased attention (Glaholt, Wu, & Reingold, 2009; Viaene, Vansteenkiste, Lenoir, Wulf, & Maeyer, 2016). Increased viewing time indicates interest or engagement that is often linked to complexity (Duchowski, 2007; Holmqvist et al., 2011). Failing to achieve both may suggest a sense of oppression and boredom.

The gaze-tracking in P2018 demonstrate a more dynamic and engaged visual exploration than in P2015, particularly at the beginning of the exploration. This indicates that people are likely to get a more holistic view of the proposed development in the more developed later phase. The overall higher voxel numbers and viewing time in the P2018 phase reveal participants' interest in the more complex virtual model. This is in line with Kaplan and Kaplan (1989), who highlight the importance of complexity.

Comparing viewing patterns at each waypoint of the two phases exposes perceptual differences regarding various spatial features. For instance, Waypoints 2–7 received higher exploration counts in P2018 than in P2015, indicating participants' increased willingness to explore the area. Participants spent longer time at Waypoints 9–12 in P2018 and Waypoints 3–4 in P2015, which suggests a higher level of complexity of the relevant area. Notably, the turning points of visual engagement in the VEs (i.e., Waypoints 3, 5, 8, and 12) coincided with areas where the degree of spatial enclosure changed, which is defined by the ratio of the height of buildings to the width of the street. This supports previous research on the degree of enclosure and perceptual responses (e.g. Fisher-Gewirtzman, 2018; Stamps & Smith, 2002).

The 3D exploratory patterns have unveiled some common features among the two planning phases. In both planning phases, towards the end of the virtual journey there is a decline in engagement time and voxel numbers. One reason for this might be a lack of complexity and attractiveness, meaning the environment was interpreted more easily by participants. It could also suggest 'visual fatigue' during the viewing experience (Wang et al., 2019). As a result, order bias may appear in reported perceptions of the pre-designed journey. Future research could address this issue by introducing a reverse journey or exposing participants to random travel routes.

Not surprisingly, reflecting the nature of a low-rise urban environment, previous eye-gaze tracking carried out in a real low-rise environment (e.g. Simpson et al. (2019)), indicate the impact of ground floors, as pedestrians are mostly perceiving the city at eye level. Despite situated in a high-rise context, in this study the main focus of the participants' gaze pattern was also on the lower-storey environment in both planning phases. This provides empirical backing for Gehl (2013) and Glaser, van'T Hoff, Karssenberg, Laven, and van Teeffelen (2012) who highlight the importance of the qualities of the ground floor for urban design practices. The result also informs planning and design for pedestrian-friendly environments (Watson, 2003). For example, building upon the findings of Trossman Haifler and Fisher-Gewirtzman (2020), combining commercial activity and vegetation in lower-level areas could enhance pedestrian wellbeing in high-rise environments.

4.2. Participants preferences and perceptions of the two planning phases

P2018 was slightly preferred over P2015 in terms of level of detail, beauty and uniqueness in the SDS evaluation; In addition, participants had a superior landmark recall of the P2018 phase compared to that of the P2015. This is in line with the more concentrated and prolonged gaze-tracking pattern in P2018 and suggests that a distinct and clear form of architecture could create a legible and imageable environment of the development (e.g. Lynch, 1960; Shushan, Portugali, & Blumenfeld-Lieberthal, 2016).

Only marginal differences were found in the estimations of height and number of buildings as well as the distance travelled between the two planning phases. Although perceptions of the regulatory indices did not differ greatly regarding the two planning phases, both groups underestimated these indices in the VE. This might be explained by the gaze pattern of the participants, as they have primarily focused on the lower parts, thus not realising the height of the buildings. Also, misperceptions of scale in computer generated visualisations was highlighted in a number of studies (Watzek & Ellsworth, 1994; Willis et al., 2009). Therefore, in the planning and design disciplines one needs to be cautious when transferring experimental results using virtual representations as e.g. in a head-mounted VR device directly into the real world.

In both SDS evaluation and spatial tests, the personal differences between the two planning phases were subtle. No significant differences in spatial perception were found between male and female participants. This is consistent with Coluccia and Louse (2004), a review of experiments concerning gender difference in spatial perception. In contrast to previous studies that identified the impact of planning expertise on spatial perception (Dupont, Antrop, & Van Eetvelde, 2015; Paes et al., 2017), our study indicates that the novice groups were as capable as their counterparts in perception abilities.

Previous studies have identified a superiority in spatial perception among more highly educated participants (Hidayetoglu, Yildirim, & Cagatay, 2010; Paes et al., 2017). In contrast, our research shows that for P2018, those without university degrees actually performed better at landmark recall, scoring an average 5.2 score (out of a total of 30) higher

Table 2
Difference of estimation and reality by phase.

	Estimation – Reality difference			Landmark recall balanced score
	Height (Height – 200) m	Number (Disparity rate)	Distance (Distance – 2671) m	
	Median (95.0% CI)	Median (95.0% CI)	Median (95.0% CI)	Mean (SD)
Phase 2015	−95 (−120,0)	−0.08 (−0.37, 0.26)	−2566 (−2591, −2471)	2.12*** (7.09)
Phase 2018	−90 (−100,0)	−0.07 (−0.29, 0.43)	−2561 (−2571, −2471)	4.82*** (4.27)

Note: "***" indicates significant difference, $p < 0.05$.

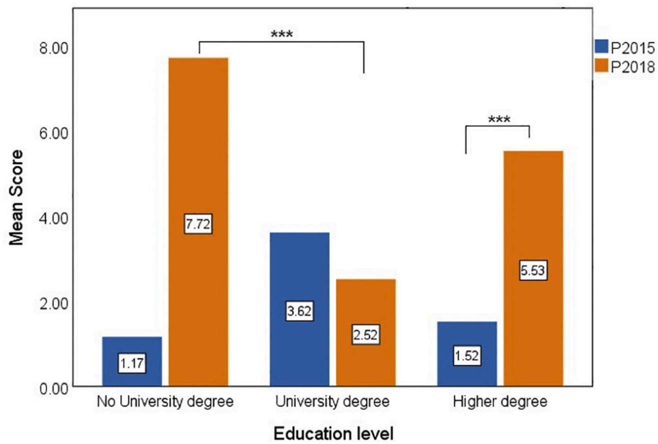


Fig. 10. Clustered bar mean of landmark recall score in the two phases by education level.
"***" remarks a statistically significant difference between the different subgroups.

than those with university degrees. Although the SDS results indicated that first time VR users may differ from experienced ones in their perception of the device, their performances in landmark and factual knowledge tests were not significantly different. This shows the potential of VR to more widely engage novices in planning and decision-making (Portman, Natapov, & Fisher-Gewirtzman, 2015).

Some of the discrepancies between previous test results and ours might be explained by our approach. We used a complex immersive 3D environment instead of a 2D or 3D small-scale setting as often employed in previous studies. It could also be linked to the type of questions that were asked in the experiment, as we primarily focused on survey and landmark knowledge. Testing spatial abilities through other dimensions of knowledge could lead to different responses.

5. Conclusion

This study was designed to investigate how the public perceives two planning phases (2015 and 2018) of a new high rise development project. The two phases are characterised by subtle differences. The automated 3D gaze-tracking provides a quantitative and objective supplement to early research on dynamic vision in urban settings. It has led to a deeper understanding of participants' spatial perceptions and preferences, indicating e.g. areas of higher interest and complexity, which in turn could influence planning and design practice. Building on our approach there is scope for further research in developing evaluation models and testing preferences in the context of alternative planning proposals. In terms of participants' SDS evaluation and spatial knowledge testing, the results reveal marginal differences between socio-demographic characteristics (gender, planning expertise, VR experience and education level) in perceptions of regulatory indices as expressed in the two phases. This suggests that there is potential for the wider public to play a more substantial role in different stages of the planning and design process. Representations with higher levels of complexity, typically available in later planning phases help to improve landmark recall. Future studies could extend the scope of this research and place it on a broader basis by covering a wider timeframe as planning proposals develop over time from the initial conception to the final realisation.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compenvurbsys.2021.101685.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

Acknowledgement

This research is supported by the Joint China Scholarship Council – University of Sheffield PhD programme [No. 201706090252]; and the Newton Fund/Engineering and Physical Sciences Research Council (EPSRC) as part of the Sustainable Deltas award [No. P/R024979/1]. The Adaptive Urban Transformation research project is a collaborative project of the University of Sheffield, South China University of Technology and Delft University of Technology. We thank two anonymous reviewers for helpful comments on earlier drafts of the manuscript.

Appendix A. Participants' semantic differential scale evaluation

Factors		Mean of semantic differential scale (Standard deviation)													
Total		Not helpful for understanding-helpful for understanding		Hard to use-easy to use		Abstract- realistic		Simple- detailed		Boring-interesting		Ugly- beautiful		Repetitive-unique	
		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
Overall		P 2015	P 2018	P 2015	P 2018	P 2015	P 2018	P 2015	P 2018	P 2015	P 2018	P 2015	P 2018	P 2015	P 2018
		4.7(0.5)	4.5 (0.9)	4.9 (0.4)	4.7 (0.6)	3.6 (1.1)	3.8 (1.0)	3.0 (1.2	3.4 (1.1)	4.3 (0.9)	4.3 (0.9)	3.7 (1.0)	3.8 (1.0)	3.6 (1.2)	3.9 (1.1)
Gender	Female	4.6 (0.5)	4.4 (0.9)	4.9 (0.5)	4.8 (0.4)	3.6 (1.2)	4.0 (1.0)	3.0 (1.2)	3.4 (1.3)	4.3 (0.9)	4.1 (1.1)	3.6 (1.2)	3.8 (1.0)	3.6 (1.2)	3.9 (1.1)
	Male	4.7 (0.45)	4.5 (0.8)	4.8 (0.4)	4.6 (0.8)	3.6 (1.0)	3.7 (1.0)	3.0 (1.2)	3.5 (1.0)	4.4 (0.8)	4.5 (0.6)	3.7 (0.7)	3.9 (1.0)	3.7 (1.3)	3.9 (1.1)
Education level	No University degree	4.8 (0.41)	4.5 (1.2)	4.8 (0.4)	4.8 (0.4)	3.3 (1.9)	3.7 (1.0)	2.7 (1.5)	3.2 (1.5)	4.5 (0.5)	4.7 (0.5)	4.3 (0.8)	4.0 (1.3)	4.3 (0.8)	4.2 (0.8)
	University degree	4.8 (0.44)	4.4 (0.9)	4.9 (0.3)	4.7 (0.5)	4.1 (0.8)	4.1 (1.0)	3.1 (1.1)	3.8 (1.1)	4.0 (1.2)	4.3 (0.9)	3.5 (1.4)	3.9 (1.0)	3.8 (1.2)	4.2 (1.1)
	Higher degree	4.6 (0.51)	4.5 (0.8)	4.8 (0.5)	4.7 (0.7)	3.4 (1.0)	3.7 (1.0)	3.0 (1.2)	3.3 (1.1)	4.5 (0.7)	4.2 (1.0)	3.6 (0.7)	3.8 (1.0)	3.4 (1.3)	3.6 (1.2)
Lay or professional	Professional	4.6 (0.51)	4.6 (0.7)	4.9 (0.3)	4.8 (0.4)	3.5 (1.1)	3.9 (0.9)	2.8 (1.3)	3.3 (0.9)	4.4 (0.5)	3.9 (1.1)	3.4 (1.0)	3.8 (0.9)	3.5 (1.1)	3.7 (1.1)
	Laypeople	4.7 (0.47)	4.4 (0.9)	4.8 (0.5)	4.7 (0.6)	3.6 (1.1)	3.8 (1.1)	3.1 (1.1)	3.5 (1.2)	4.3 (1.0)	4.4 (0.8)	3.8 (1.0)	3.8 (1.1)	3.7 (1.3)	4.0 (1.1)

(*continued on next page*)

(*continued*)

Factors		Mean of semantic differential scale (Standard deviation)													
Total		Not helpful for understanding- helpful for understanding		Hard to use- easy to use		Abstract- realistic		Simple- detailed		Boring- interesting		Ugly- beautiful		Repetitive- unique	
		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
VR experience	Yes	4.5 ^^^ (0.51)	4.4 (1.0)	4.8 (0.4)	4.6 (0.7)	3.4 (1.2)	3.5^^^ (1.1)	2.7 (1.1)	3.3 (1.2)	4.3 (0.7)	4.0 (1.0)	3.8 (0.9)	3.9 (1.0)	3.6 (1.1)	3.7 (1.2)
	No	4.8 ^^^ (0.39)	4.5 (0.8)	4.9 (0.5)	4.8 (0.4)	3.7 (1.1)	4.1^^^ (0.9)	3.2 1.2)	3.6 (1.1)	4.4 (1.0)	4.5 (0.8)	3.6 (1.1)	3.8 (1.0)	3.7 (1.3)	4.0 1.0)

"***" The significance level of between-phase comparison is <0.05; "^^^" The significance level of within-phase comparison is <0.05.

Appendix B. Estimation − Reality difference of participants' knowledge tests

Factors		Estimation − Reality difference						Landmark recall	
		Height (Height − 200) m		Number (Disparity rate)		Distance (Distance − 2671) m		Balanced score	
		Median (95.0% CI)		Median (95.0% CI)		Median (95.0% CI)		Mean (SD)	
Total		P 2015 −95 (−120, 0)	P 2018 −90 (−100, 0)	P 2015 −0.08 (−0.37, 0.26)	P 2018 −0.07 (−0.29, 0.43)	P 2015 −2566 (−2591, −2471)	P 2018 −2561 (−2571, −2471)	P 2015 2.12*** (7.09)	P 2018 4.82*** (4.27)
Gender	Female	−40 (−103,100)	−100 (−100, 0)	−0.21 (−0.47, 0.58)	−0.29 (−0.29, 0.43)	−2511 (−2547, −2371)	−2571 (−2571, −2471)	2.09 (5.86)	4.41 (4.49)
	Male	−120 (−125, 0)	−50 (−120,100)	0.05 (−0.21, 1.63)	0.25 (−0.29, 0.43)	−2591 (−2596, −2471)	−2521 (−2591, −2371)	2.16 (8.51)	5.32 (4.04)
Education level	No University degree	0 (−100, 500)	0 (−100,300)	−0.21 (−0.74, 0.58)	−0.18 (−0.43, 0.21)	−2471 (−2571, −1971)	−2471 (−2571, −2171)	1.17 (8.26)	7.72 ^^^ (4.53)
	University degree	−80 (−140, 100)	−50 (−100, 225)	0.26 (−0.37, 1.63)	−0.21 (−0.50, 0.43)	−2551 (−2611, −2371)	−2521 (−2571, −2246)	3.62 (7.97)	2.52 ^^^ (4.40)
	Higher degree	−102 (−125, −20)	−100 (−115, −50)	−0.21 (−0.37, 0.26)	0.43 (0.43, 1.14)	−2573 (−2596, −2491)	−2571 (−2586, −2521)	1.52 *** (6.44)	5.53*** ^^^ (3.60)
Lay or professional	Professional	−103 (−125, 25)	−100 (−115, 50)	0.16 (−0.37, 1.37)	0.07 (−0.29, 0.43)	−2574 (−2596, −2446)	−2571 (−2584, −2421)	1.42 (6.32)	5.71 (4.93)
	Laypeople	−88 (−−120,0)	−90 (−100, 0)	−0.21 (−0.47, 0.26)	−0.18 (−0.29, 0.43)	−2559 (−2591, −2471)	−2561 (−2571, −2471)	2.40 (7.45)	4.45 (3.98)
VR experience	Yes	−103 (−120, −40)	−95 (−150, 0)	0.26 (−0.21, 1.11)	0.43 (0.07, 1.14)	−2574 (−2591, −2511)	−2566 (−2621, −2471)	2.74 (9.48)	5.45 (3.22)
	No	−10 (−125, 100)	−85 (−100, 0)	−0.37 (−0.47, 0.05)	−0.29 (−0.29, 0.43)	−2481 (−2596, −2371)	−2556 (−2571, −2471)	1.61 (4.41)	4.25 (5.04)

"***" The significance level of between-phase comparison is <0.05; "^^^" The significance level of within-phase comparison is <0.05.

References

Adams, D. (1994). *Urban planning and the development process*. Psychology Press.
Amado, M. P., Santos, C. V., Moura, E. B., & Silva, V. G. (2010). Public participation in sustainable urban planning. *International Journal of Human and Social Sciences, 5*(2), 102–108.
Amati, M., Parmehr, E. G., McCarthy, C., & Sita, J. (2018). How eye-catching are natural features when walking through a park? Eye-tracking responses to videos of walks. *Urban Forestry & Urban Greening, 31*, 67–78. https://doi.org/10.1016/j.ufug.2017.12.013.
Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures, 46*, 23–40.
Appleyard, D., Lynch, K., & Myer, J. R. (1964). *The view from the road* (Vol. 196, no. 3). Cambridge, MA: MIT press.
Bacon, E. N. (1967). *Design of cities*. Viking Press.
Banerjee, T., & Loukaitou-Sideris, A. (Eds.). (2011). *Companion to urban design*. Routledge.
Bishop, I. D. (2015). Location based information to support understanding of landscape futures. *Landscape and Urban Planning, 142*, 120–131. https://doi.org/10.1016/j.landurbplan.2014.06.001.
Bishop, I. D., Pettit, C. J., Sheth, F., & Sharma, S. (2013). Evaluation of data visualisation options for land-use policy and decision making in response to climate change. *Environment and Planning. B, Planning & Design, 40*(2), 213–233. https://doi.org/10.1068/b38159.
Blascheck, T., Kurzhals, K., Raschke, M., Burch, M., Weiskopf, D., & Ertl, T. (2014). State-of-the-art of visualization for eye tracking data. In R. Borgo, R. Maciejewski, & I. Viola (Eds.), *Eurographics conference on visualization (EuroVis)* (pp. 63–82). The Eurographics Association.
Chennamma, H. R., & Yuan, X. (2013). A survey on eye-gaze tracking techniques. *ArXiv Preprint ArXiv, 1312*, 6410.
Coluccia, E., & Louse, G. (2004). Gender differences in spatial orientation: A review. *Journal of Environmental Psychology*. https://doi.org/10.1016/j.jenvp.2004.08.006.
Cubukcu, E., & Nasar, J. L. (2005). Relation of physical form to spatial knowledge in largescale virtual environments. *Environment and Behavior, 37*(3), 397–417. https://doi.org/10.1177/0013916504269748.
Cullen, G. (1961). *The concise townscape*. Routledge.
Danahy, J. W. (2001). Technology for dynamic viewing and peripheral vision in landscape visualization. *Landscape and Urban Planning, 54*(1), 127–138. https://doi.org/10.1016/S0169-2046(01)00131-1.
Dockerty, T., Lovett, A., Appleton, K., Bone, A., & Sünnenberg, G. (2006). Developing scenarios and visualisations to illustrate potential policy and climatic influences on

future agricultural landscapes. *Agriculture, Ecosystems & Environment, 114*(1), 103–120. https://doi.org/10.1016/j.agee.2005.11.008.
Dockerty, T., Lovett, A., Sünnenberg, G., Appleton, K., & Parry, M. (2005). Visualising the potential impacts of climate change on rural landscapes. *Computers, Environment and Urban Systems, 29*(3), 297–320. https://doi.org/10.1016/j.compenvurbsys.2004.05.004.
Dorr, M., Martinetz, T., Gegenfurtner, K. R., & Barth, E. (2010). Variability of eye movements when viewing dynamic natural scenes. *Journal of Vision, 10*(10), 28. https://doi.org/10.1167/10.10.28.
Duchowski, A. T. (2007). Eye tracking methodology. *Theory Into Practice, 328*(614), 2–3.
Dupont, L., Antrop, M., & Van Eetvelde, V. (2015). Does landscape related expertise influence the visual perception of landscape photographs? Implications for participatory landscape planning and management. *Landscape and Urban Planning, 141*, 68–77. https://doi.org/10.1016/j.landurbplan.2015.05.003.
Dupont, L., Ooms, K., Antrop, M., & Van Eetvelde, V. (2016). Comparing saliency maps and eye-tracking focus maps: The potential use in visual impact assessment based on landscape photographs. *Landscape and Urban Planning, 148*, 17–26. https://doi.org/10.1016/j.landurbplan.2015.12.007.
Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. SAGE.
Fisher-Gewirtzman, D. (2018). Perception of density by pedestrians on urban paths: An experiment in virtual reality. *Journal of Urban Design, 23*(5), 674–692. https://doi.org/10.1080/13574809.2018.1444471.
Gehl, J. (2013). *Cities for people*. Island press.
Ghasemi, A., & Zahediasl, S. (2012). Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology and Metabolism, 10*(2), 486–489. https://doi.org/10.5812/ijem.3505.
Glaholt, M. G., Wu, M.-C., & Reingold, E. M. (2009). Predicting preference from fixations. *PsychNology Journal, 7*(2), 141–158.
Glaser, M., van'T Hoff, M., Karssenberg, H., Laven, J., & van Teeffelen, J. (2012). *The city at eye level: Lessons for street plinths*. Eburon Academic Publishers.
GOVUK. (2018). High Speed 2 design and development: Detailed information. Retrieved from https://www.gov.uk/topic/high-speed-2/design-development (August 7).
Han, Y., & Peng, Z. (2019). The integration of local government, residents, and insurance in coastal adaptation: An agent-based modeling approach. *Computers, Environment and Urban Systems, 76*, 69–79. https://doi.org/10.1016/j.compenvurbsys.2019.04.001.
Hersperger, A. M., Oliveira, E., Pagliarin, S., Palka, G., Verburg, P., Bolliger, J., & Grădinaru, S. (2018). Urban land-use change: The role of strategic spatial planning. *Global Environmental Change, 51*, 32–42. https://doi.org/10.1016/j.gloenvcha.2018.05.001.
Hidayetoglu, M. L., Yildirim, K., & Cagatay, K. (2010). The effects of training and spatial experience on the perception of the interior of buildings with a high level of complexity. *Scientific Research and Essays, 5*(5), 428–439.
Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & Van de Weijer, J. (2011). *Eye tracking: A comprehensive guide to methods and measures*. OUP Oxford.
Hopkins, L. D. (2001). *Urban development: The logic of making plans*. Island Press.
Kang, J., & Zhang, M. (2010). Semantic differential analysis of the soundscape in urban open public spaces. *Building and Environment, 45*(1), 150–157.
Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. CUP Archive.
Kim, Y., & Newman, G. (2020). Advancing scenario planning through integrating urban growth prediction with future flood risk models. *Computers, Environment and Urban Systems, 82*, 101498. https://doi.org/10.1016/j.compenvurbsys.2020.101498.
Kuliga, S. F., Thrash, T., Dalton, R. C., & Hölscher, C. (2015). Virtual reality as an empirical research tool — exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems, 54*, 363–375. https://doi.org/10.1016/j.compenvurbsys.2015.09.006.
Lange, E., & Hehl-Lange, S. (2010). Making visions visible for long-term landscape management. *Futures, 42*(7), 693–699. https://doi.org/10.1016/j.futures.2010.04.006.
Lange, E., Hehl-Lange, S., & Brewer, M. J. (2008). Scenario-visualization for the assessment of perceived green space qualities at the urban–rural fringe. *Journal of Environmental Management, 89*(3), 245–256. https://doi.org/10.1016/j.jenvman.2007.01.061.
Lewis, J. L. (2012). More art than science: The sources and effects of stylistic variation in visualization for planning and design. *Environment and Planning. B, Planning & Design, 39*(3), 551–565. https://doi.org/10.1068/b37148.
Luccarelli, M., & Røe, P. G. (2016). *Green Oslo: Visions, planning and discourse*. Routledge.
Lynch, K. (1960). *The image of the city* (Vol. 11). MIT press.
Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Role of subjective and objective measures of cognitive processing during learning in explaining the spatial contiguity effect. *Learning and Instruction, 61*, 23–34.
Masser, I. (1983). The representation of urban planning-processes: An exploratory review. *Environment and Planning. B, Planning & Design, 10*(1), 47–62. https://doi.org/10.1068/b100047.
Noland, R. B., Weiner, M. D., Gao, D., Cook, M. P., & Nelessen, A. (2017). Eye-tracking technology, visual preference surveys, and urban design: Preliminary evidence of an effective methodology. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10*(1), 98–110. https://doi.org/10.1080/17549175.2016.1187197.
Omer, I., & Goldblatt, R. (2007). The implications of inter-visibility between landmarks on wayfinding performance: An investigation using a virtual urban environment. *Computers, Environment and Urban Systems, 31*(5), 520–534. https://doi.org/10.1016/j.compenvurbsys.2007.08.004.
Osgood, C. E. (1964). Semantic differential technique in the comparative study of cultures 1. *American Anthropologist, 66*(3), 171–200.
Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *Automation in Construction, 84*, 292–303. https://doi.org/10.1016/j.autcon.2017.09.016.
Pettit, C. J., Raymond, C. M., Bryan, B. A., & Lewis, H. (2011). Identifying strengths and weaknesses of landscape visualisation for effective communication of future alternatives. *Landscape and Urban Planning, 100*(3), 231–241. https://doi.org/10.1016/j.landurbplan.2011.01.001.
Pihel, J., Ode Sang, Å., Hagerhall, C., & Nyström, M. (2015). Expert and novice group differences in eye movements when assessing biodiversity of harvested forests. *Forest Policy and Economics, 56*, 20–26. https://doi.org/10.1016/j.forpol.2015.04.004.
Portman, M. E., Natapov, A., & Fisher-Gewirtzman, D. (2015). To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems, 54*, 376–384.
Ramos, I. L. (2010). Exploratory landscape scenarios' in the formulation of 'landscape quality objectives. *Futures, 42*(7), 682–692. https://doi.org/10.1016/j.futures.2010.04.005.
Roupé, M., Bosch-Sijtsema, P., & Johansson, M. (2014). Interactive navigation interface for virtual reality using the human body. *Computers, Environment and Urban Systems, 43*, 42–50. https://doi.org/10.1016/j.compenvurbsys.2013.10.003.
Roupé, M., & Gustafsson, M. (2013). Judgment and decision-making aspects on the use of virtual reality in volume studies. In *Proceedings of the 18th international conference on computer-aided architectural design research in Asia (CAADRIA 2013)* (pp. 437–446).
Salkind, N. J. (2010). *Encyclopedia of research design*. Sage Publications, Inc.
Sheppard, S. R. J. (2015). Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning, 142*, 95–105. https://doi.org/10.1016/j.landurbplan.2015.07.006.
Sheppard, S. R. J., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., … Cohen, S. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *Futures, 43*(4), 400–412. https://doi.org/10.1016/j.futures.2011.01.009.
Shih, S. W., & Liu, J. (2004). A novel approach to 3-D gaze tracking using stereo cameras. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, 34*(1), 234–245. https://doi.org/10.1109/TSMCB.2003.811128.
Shushan, Y., Portugali, J., & Blumenfeld-Lieberthal, E. (2016). Using virtual reality environments to unveil the imageability of the city in homogenous and heterogeneous environments. *Computers, Environment and Urban Systems, 58*, 29–38. https://doi.org/10.1016/j.compenvurbsys.2016.02.008.
Simpson, J., Freeth, M., Simpson, K. J., & Thwaites, K. (2019). Visual engagement with urban street edges: Insights using mobile eye-tracking. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 12*(3), 259–278. https://doi.org/10.1080/17549175.2018.1552884.
Stamps, A. E., & Smith, S. (2002). Environmental enclosure in urban settings. *Environment and Behavior, 34*(6), 781–794. https://doi.org/10.1177/001391602237246.
Steinitz, C., Arias, H., Bassett, S., Flaxman, M., Goode, T., Maddock, T., … Shearer, A. (2003). *Alternative futures for changing landscapes: The upper San Pedro River basin in Arizona and Sonora*. Island press.
Taylor, N. (1998). The systems and rational process views of planning. In N. Taylor (Ed.), *Urban planning theory since 1945* (pp. 59–74). SAGE Publications. https://doi.org/10.4135/9781446218648.n4.
Tomkins, A., Hehl-Lange, S., & Lange, E. (2019). Tracking visual engagement in mixed reality: A framework for analysing interaction with digital models. *Journal of Digital Landscape Architecture, 4*, 160–167.
Trossman Haifler, Y., & Fisher-Gewirtzman, D. (2020). Urban wellbeing, as influenced by densification rates and building typologies-A virtual reality experiment. In D. Holzer, W. Nakapan, A. Globa, & I. Koh (Eds.), *Vol. 1. RE: Anthropocene, proceedings of the 25th international conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2020* (pp. 661–670).
Viaene, P., Vansteenkiste, P., Lenoir, M., Wulf, A. D., & Maeyer, P. (2016). Examining the validity of the total dwell time of eye fixations to identify landmarks in a building. *Journal of Eye Movement Research, 9*(3), 1–11. https://doi.org/10.16910/jemr.9.3.4.
Wang, Y., Zhai, G., Chen, S., Min, X., Gao, Z., & Song, X. (2019). Assessment of eye fatigue caused by head-mounted displays using eye-tracking. *Biomedical Engineering Online, 18*(1), 111. https://doi.org/10.1186/s12938-019-0731-5.
Watson, D. (2003). *Time-saver standards for urban design*. McGraw-Hill Education.
Watzek, K. A., & Ellsworth, J. C. (1994). Perceived scale accuracy of computer visual simulations. *Landscape Journal, 13*(1), 21–36. http://www.jstor.org/stable/43324114.
Willis, K. S., Hölscher, C., Wilbertz, G., & Li, C. (2009). A comparison of spatial knowledge acquisition with maps and mobile maps. *Computers, Environment and Urban Systems, 33*(2), 100–110.
Xiang, W. N., & Clarke, K. C. (2003). The use of scenarios in land-use planning. *Environment and Planning. B, Planning & Design, 30*(6), 885–909. https://doi.org/10.1068/b2945.
Zhang, L. M., Zhang, R. X., Jeng, T. S., & Zeng, Z. Y. (2019). Cityscape protection using VR and eye tracking technology. *Journal of Visual Communication and Image Representation, 64*, 102639. https://doi.org/10.1016/j.jvcir.2019.102639.