Understanding how trace visualizations influence exploration behaviors in VR

Master Thesis

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Abstract

Understanding how the end users, ordinary citizens, experience designed public spaces is fundamental in the field of urban design. Virtual Reality (VR) technologies significantly enhance the ease of evaluating public space designs by creating virtual simulations. This allows users to immerse themselves more deeply in the space compared to traditional screen-based presentations. However, the true experience of space design only occurs once it is physically constructed. Designers still face challenges in effectively investigating how citizens might interact with the future space. In evaluating public space designs, one obstacle is that users can only provide feedback based on individual experiences, lacking knowledge of how others have perceived or used the space, which contrasts with the real world situations where people experience and perceive public spaces with the association with how others' experiences.

Trace visualizations have been used to analyze user behaviors. Visualizing traces of previous users unlocks possibilities of enhancing curiosity and meaningful exploration of the space, which could inspire more association about use scenarios and a deeper understanding of the spatial properties, and eventually benefit the evaluation outcomes.

This project explored the influences of visualizing human traces on users' explorative behaviors in virtual reality space. We started with conducting interviews with urban designers to understand the utilization of traces in the processes of public space design and their perspectives regarding implementing trace visualizations to support public space design evaluation. Insights from the interview informed the selection of traces for the experiment including user pathways, gathering situation, full-body motion, and space atmosphere. Subsequently, we integrated trace visualizations into a VR shopping street and conducted the experiment with 20 participants to evaluate the impacts of each trace visualization on user exploration. The outcomes from interviews and operational activities undertaken by participants revealed exploration patterns associated with each type of the trace visualizations and related findings concerning user perceptions of the trace visualizations. The project concluded with the implications for implementing trace visualizations in VR environments and the limitations of the research.

Chapter 1: Introduction

Intro

This chapter introduces the challenge of presenting urban design outcomes regarding how to exhibit an outdoor public space in a way that allows general citizens to better associate the space usage, and the potentiality of addressing this issue by visualizing traces of previous users' actions. The chapter concludes with the research question: "How does observing trace visualizations affect users' explorative behaviors in virtual environments?"

Overview

1.1 Project Context

1.1.1 Urban Design Evaluation

Conventionally, in the field of urban design, decisions regarding outdoor public space design are made largely without comprehensive understanding of the end users. In pursuit of more democratic cities, scholars advocate for participatory approaches (Dyer et al., 2017; Mueller et al., 2018; Faliu et al., 2019) that involve citizens in the entire process of public space design – from understanding user behaviors before designing to prototyping spaces and evaluating design outcomes. The involvement of citizens in the evaluation of public space designs has proven valuable especially with the supports of added digital 3D environments, fostering increased engagement and understanding of the space, ultimately leading to improved design outcomes (Dembski et al., 2020; Van Leeuwen et al., 2018). In real practice, various presentation methods are employed to facilitate the evaluation of public space design, including screen-based presentations, virtual tours using rendering software, and VR-empowered evaluations.

Screen-based presentations, the conventional method, involve urban designers showcasing design outcomes through rendered images capturing specific angles and functions of the space. Accompanied by the images, urban designers verbally explain their design and the expected use situations. This method heavily relies on designers' narrative skills and citizens can only understand limited aspects of the public space with their imagination.

A more advanced method involves conducting a guided virtual tour using rendering software, commonly employed in educational and commercial settings for projects promoting citizen participation or redesigning urban spaces. Citizens are given basic control of the camera within the rendering software, providing them with more freedom to observe the public space compared to screen-based presentations

For a more comprehensive evaluation of public spaces, many urban designers turn to VR-empowered evaluations. Urban designers create a VR simulation of the public space aligned with their designs, allowing citizens to explore the space from a first-person perspective. This kind of VR-empowered evaluation provides a high level of immersion and spatial awareness that nurture a holistic understanding of the public space.

However, despite the support of VR technology, effectively investigating how citizens will use public spaces remains challenging for designers. A specific challenge in public space design evaluation is that users can only provide feedback on an individual basis, unaware of how others may experience or use the space. This contrasts with real-world situations where people experience and perceive public spaces with associations with others' experiences. This challenge necessitates a new way of presenting public spaces.

1.1.2 Visualizing Human Traces

A potential solution for addressing the problem of "limited understanding of other users behaviors" is to visualize traces of human actions. The effect of visualizing traces has proven effective in works of public displays (Müller et al., 2012; Chomko & Rosier, 2015; EL-Zanfaly et al., 2022), enhancing public engagement and fostering meaningful interactions.

In the realm of virtual reality (VR), innovative VR systems have adopted the visualization of traces to showcase the outcomes of outdoor public space designs. For instance, the Olifantenpad CS (Martens & Manders, 2021), designed to facilitate collaborative outdoor public space planning, incorporates traces to portray full-body human motion. This visualization method effectively illustrates the social activities enabled by the designed public space.

Figure 1.1: Memory Portal
(EL-Zanfaly et al., 2022)

Figure 1.2: Shadowing
(Chomko & Rosier, 2015)

Visualizing traces of previous users can be used as subtle social cues that can influence users' perceptions of a space and their explorative behaviors. A recent example is "Trace" (Monastero & McGookin, 2018), a public display of user pathways in a large interior public space. The displayed pathways were found to enhance users' social awareness and engagement, implicitly affecting the way users explore the space. Integrating such trace visualizations into the evaluation process of outdoor public space designs has the potential to elevate users' curiosity and promote more meaningful exploration. This, in turn, may inspire deeper associations with usage scenarios and enhance the understanding of spatial properties, ultimately benefiting the overall evaluation outcomes.

Nevertheless, human traces can be visualized in various ways with different focuses on specific aspects of information. For instance, a visualized footprint may convey a person's movement without detailing the motion of their upper body, while a realistic 3D representation of a moving person could be valuable for inferring their emotions without highlighting the areas where they spend the most time. Nevertheless, human traces can be visualized in various ways with different focuses on specific aspects of information. For instance, a visualized footprint may convey a person's movement without detailing the motion of their upper body, while a realistic 3D representation of a moving person could be valuable for inferring their emotions without highlighting the areas where they spend the most time.

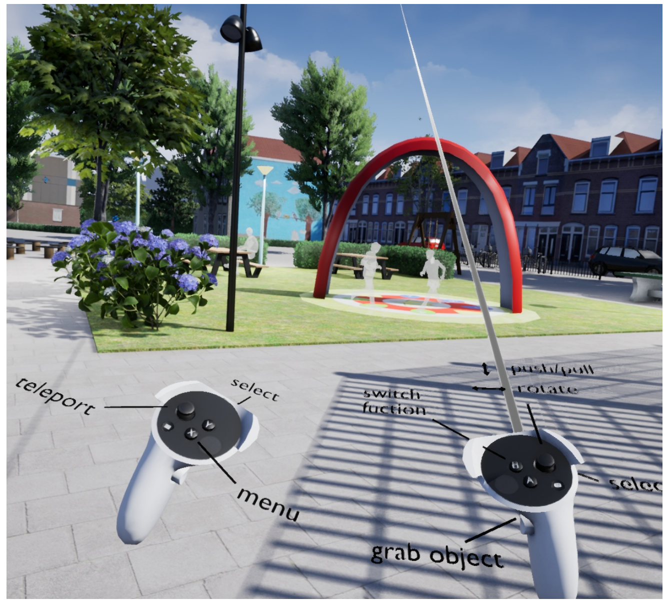


Figure 1.3: Olifantenpad CS
(Martens & Manders, 2021)

The choice of trace visualizations can lead users to form diverse speculations about potential use scenarios, consequently influencing how they perceive and explore the public space. The impact of different types of trace visualizations on perception and exploratory behaviors in the VR presentation of an outdoor public space remains an open question.

1.2 Project Direction

In summary, traditional screen-based presentations offer a limited perspective of a space, showcasing specific angles, functions, and ideal usage scenarios while in a VR-empowered evaluation session, enabling a large number of users to experience the virtual space simultaneously can be costly. To bring a more holistic experience to citizen users and yield better evaluation outcomes, it becomes valuable to allow individual users to have an understanding of how other users have used the space.

Aiming to achieve this goal, the visualization of traces left by previous users serves as social cues in the virtual public space, offering additional layers of information. This, in turn, has the potential to drive more meaningful evaluation outcomes for public space design.

What remains unexplored is how to effectively incorporate trace visualizations in a virtual public space to encourage further exploration and thoughtful understanding of the environment. Considering that different types of trace visualizations may foster diverse associations and explorative behaviors, the research question is framed as follows:

"How does observing trace visualizations affect users' explorative behaviors in virtual environments?"

For answering this question, a research tool needs to be designed along with a set of experiment protocol and trace visualizations.

Chapter 2: Related Works & Pre-study

Intro

This chapter introduces the current research regarding the VR applications in urban design domain and the implementation of trace visualizations. Through conducting a pre-study, we specified types of trace visualizations for this study and discuss application examples of each type of trace visualizations in the VR domain.

Overview

2.1 VR Applications in Urban Design

The integration of VR into urban design practices has been extensively discussed in the literature (Luigi et al., 2015; Jamei et al., 2017). Presently, research on VR applications in urban design focuses on assessing the impact of 3D visualizations of environments on enhancing user engagement (Pouke et al., 2019; Chassin et al., 2022; Jaalama et al., 2022; Ehab & Heath, 2023) and advancing the digitalization of urban co-design (Steen et al., 2013; Sanchez-Sepulveda et al., 2019). However, there is limited exploration into techniques that present potential usage scenarios and encourage individual users to speculate on how public spaces would be collectively utilized. Therefore, beyond merely presenting 3D models of buildings, streets, and plants, we would like to integrate human traces as a way to present usage scenarios of public spaces.

2.2 Visualizing Human Traces

"Traces" are understood as manifestations of prior interactions or experiences (Rosner et al., 2013). Material traces have been shown to influence people's perceptions of public spaces and enhance asynchronous social presence (Hirsch et al., 2022). With the advancements in technology, the types of traces that can be created and actively utilized extends beyond materiality. Virtual reality unlocks new possibilities for applying traces, since it allows not only the simulation of physical spaces, but also the creation of enhanced social cues that go beyond the real world experiences (McVeigh-Schultz & Isbister, 2021), such as visualizing the movements of previous users' avatars with cone of view (Fernandez-Nieto et al., 2022; Chow et al., 2019), replaying full-body motions (Fender & Holz, 2022), and users' biosignals (Hirsch et al., 2023).

In addition to facilitate active analysis of users' motions (Ieronutti et al., 2005; Kloiber et al., 2020), researchers have demonstrated the potential of using trace visualizations to guide user orientation (Kraus et al., 2020) by allowing users to leave traces as they move. However, the application of trace visualizations in facilitating exploration in VR outdoor environments and their potential benefits in the field of urban design evaluation remain unclear.

Figure 2.1: MAVRC system
(Chow et al., 2019)

Figure 2.2: AsyncReality
(Fender & Holz, 2022)

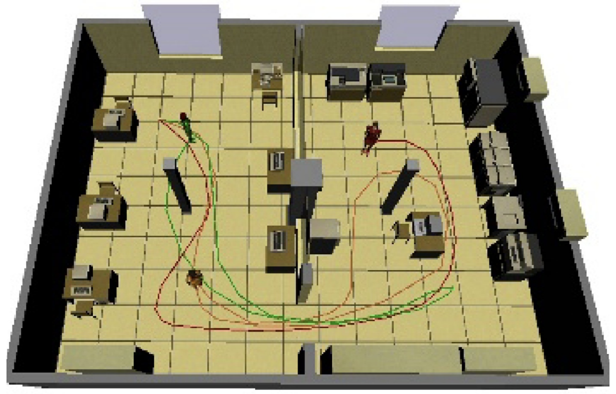
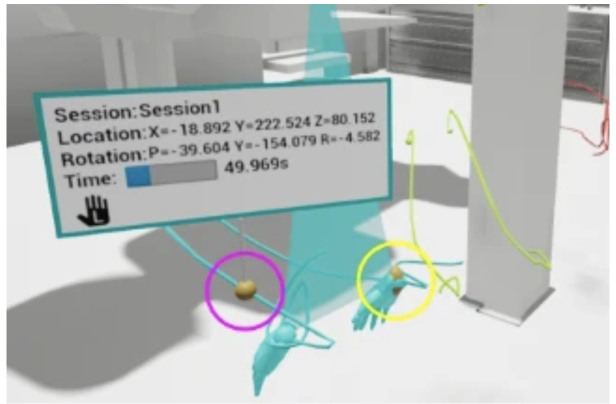


Figure 2.3: VU-Flow
(Ieronutti et al., 2005)



Session:Session1
Location:X=-18.892 Y=222.524 Z=80.152
Rotation:P=-39.604 Y=-154.079 R=-4.582
Time: 49.969s

Figure 2.4: System proposed
by Kloiber et al. (2020)

2.3 Pre-study

To understand how the visualizations of human traces are used in the processes of public space design, and urban designers' opinions regarding how they can be used in supporting the evaluation of outdoor public spaces. We carried out interviews with 6 participants who have urban design experience.

1.1.2 Visualizing Human Traces

Participants

The interviewees were recruited by snowball sampling. four interviewees were Master's students in the Faculty of Architecture and the Built Environment with varied backgrounds (Architecture, Landscape Architecture, and Urban Planning), and the other two interviewees were design practitioners previously working in the urban design industry. All the interviewees had experience in designing outdoor public spaces either in educational or commercial settings.

Participant No.	Gender	Age	Professional background	Urban design experience
P1	Male	24	Architecture	Student + Internship
P2	Female	24	Architecture	Student + Internship
P3	Female	25	Urban Planning	Student + Internship
P4	Female	26	Landscape Architecture & UX Design	Former practitioner
P5	Female	29	Landscape Architecture	Former practitioner
P6	Female	26	Urban Planning	Student + Internship

Table 2.1: Participant information

Recruitment criteria

As the purpose of the interview is to understand the current urban design practices and identify situations that could be ameliorated by trace visualizations, the only requirement for participants is having experience in conducting public space design. The experience of using VR was considered less important in this case since 1) urban designers who did not have VR experience might provide novel ideas without considering the current technical limitations; 2) It was difficult to find participants with relevant experience as VR is still not a prevalent tool used in the urban design process.

Interview set-up

The interview was set to 45-60 minutes via Zoom. Considering all the interviewees are Chinese, the interviews were conducted in Mandarin. The audio recording and transcribing were processed using iFLYREC. The consent form was shared with the participants before the start.

Interview questions

The interview was set to two phases: 1) Understanding the current urban design practice, and 2) Speculating the use of trace visualizations.

The first phase started by asking the interviewee to introduce one of public space design projects they have been working on. After the introduction, a series of follow-up questions were asked to specifically inquire about the methods used for studying end users' behaviors in a given space and how those methods would affect design outcomes. To launch the second phase, 5 trace visualizations were introduced to the interviewee. Following the introduction, the interviewee will be asked to speculate what type of traces could be helpful in learning user behaviors and in what ways urban designers might be able to use them.

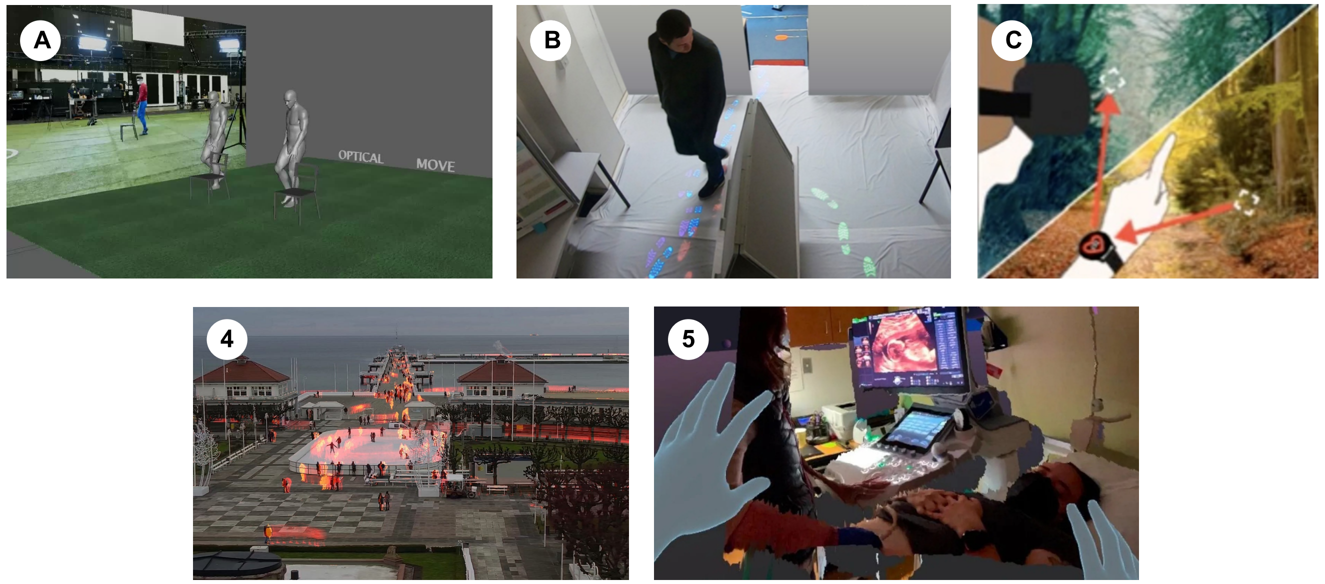


Figure 2.1: Cases of trace visualizations

1. Full-body motion capture (Moved.ai); 2. Floor-displayed pathway (Albarrak et al., 2021); 3. Emotion visualization (Stellmacher et al., 2021); 4. Heatmap of users' length of stay (Roberto., 2020); 5. Converting video recording into VR environment (Wistlabs.com)

2.3.2 Findings

Responses from the interview were collected and analyzed. The results shown the types of information that are used for urban designers to understand the usage of public spaces, the current ways of how they use traces in their practice, and their expectations regarding using trace visualizations to support evaluation of public space design.

Information expected for understanding public space

When conducting field observation, urban designers collect several key information to help identify the situation of space usage and citizens' expectations of the improvements of the public space: 1) Users' pathways; 2) Detailed user behaviors and the types of activities; 3) Users' subjective feelings about the space; 4) Users' expectations for space improvement; 4) When users use the space and how long they stay in the space; 5) User distribution and places for social gathering; 6) Traffic situations. These information will be combined with urban designers' subjective feelings of the atmosphere of the space to conclude a design theme or direction.

Urban designers have adopted multiple ways of visualizing traces

Urban designers usually record user pathways with drawings on a 2D map. 1) Line is commonly used for both recording user pathways and presenting them to clients; 2) The aggregate of lines forms a simplistic heatmap, informing users' gathering locations. In some situations, urban designers can acquire heatmaps of gathering situations from their clients or public services; 3) When presenting design outcomes, 3D animated characters are used to better convey the atmosphere of the public space or emphasize specific functions afforded by the public space; 4) Urban designers create collages composed of colors, images, silhouettes to help them perceive and present the atmosphere of the public space.

Urban designers expectations of using trace visualizations

Urban designers expect that implementing trace visualizations can facilitate end users and clients to understand the design decisions: "*When you present your work and try to convince others, that intuitive stuff is always more impactful than abstract ones. So I think one application scenario could be in the design phase [understanding user behaviors before designing], but it will be more useful when presenting your work*" (P1). Trace visualizations may also be used to demonstrate atmosphere, which could make the presented public space more immersive: "One benefit I can think of is related to demonstrating atmosphere. If we can compose, like, we imagine there is a certain atmosphere of events, the audiences will be more immersed into the scene" (P4). Further, implementing trace visualizations may spark speculations about potential use situations: "I was thinking whether it's possible to visualize what you have done, and how a person were interacting with facilities and plants. It may give users some special feelings about the space" (P3), "It may give them [end users] inspirations, like 'this place can also be like that'. And they [end users] will also help us generate more inspirations. It's a mutual effect" (P6). Specifically, interviewees (P5, P6) stressed the importance of presenting trace visualizations in multiple layers.

2.4 Trace Visualizations in VR

The interview results helped us in choosing trace types. According to the key information for understanding public spaces (see Section 2.3.2), four types of traces can be visualized: 1) user pathway, 2) gathering situation, 3) detailed user behaviors, and 4) space vitality (representing the overall atmosphere of the space). The traffic situation was excluded as we focus on visualizing human actions. Lastly, user expectation of potential improvements refers to detailed suggestions regarding the public space design, and thus, cannot be visualized.

2.3.1 User Pathway

A recent study by Monastero and McGookin (2018) implemented displayed user pathways as a social cue, enhancing social awareness and subtly influencing users' exploration in physical spaces. Furthermore, Albarrak et al. (2021) conducted research demonstrating that visualizing traces of walking patterns can influence path choice and decision-making behaviors. These studies uncovered potential impacts of visualizing previous users' pathways on the exploratory behaviors of current users. However, it's important to note that these studies were conducted in confined indoor physical spaces, instead of in a VR outdoor public space. Therefore, it would be valuable to investigate how visualizing pathways may operate in a VR environment.

Figure 2.2: “Traces”
(Monastero & McGookin, 2018)

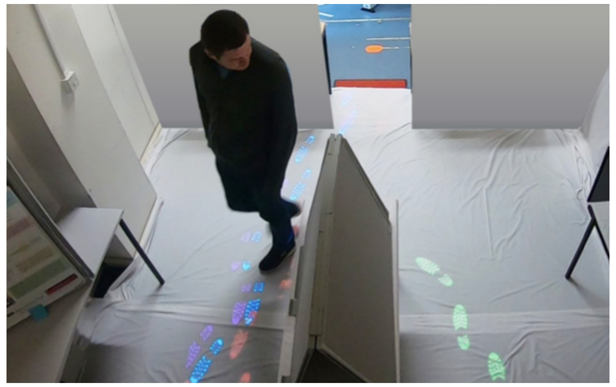


Figure 2.3: Displayed pathway
(Albarrak et al., 2021)

2.3.2 Gathering Situation

In the context of visualizing users' gathering situations, heatmaps are commonly employed to indicate the length of staying time (Luo et al., 2023) and population density. The evaluation of the influences of heatmap on navigational decisions has been explored in studies such as Albarrak et al. (2020) and Kraus et al. (2020). However, Albarrak's study (2020) assessed the influence of heatmaps by having participants observe 2D images and make path choices, while Kraus (2020) utilized heatmaps to highlight areas previously visited by current users rather than depicting the movements of previous users. How the heatmap, serving as a social cue for previous gathering situations, may impact user exploration in virtual reality outdoor public spaces is not yet clear.

2.3.3 Detailed User Behaviors

The presence and actions of other people can have a noticeable effect on one’s navigational decisions (Dalton et al., 2019), known as social navigation, and thus is considered highly valuable when designing outdoor public spaces (Mehta, 2009) and spatial-related interactive experiences (Escamilla et al., 2021). Research has shown that the effect of social navigation also applied on the VR setting (Yassin et al., 2021). Nevertheless, the influence of human motion on more detailed explorative behaviors in a free exploration context remains unexplored.

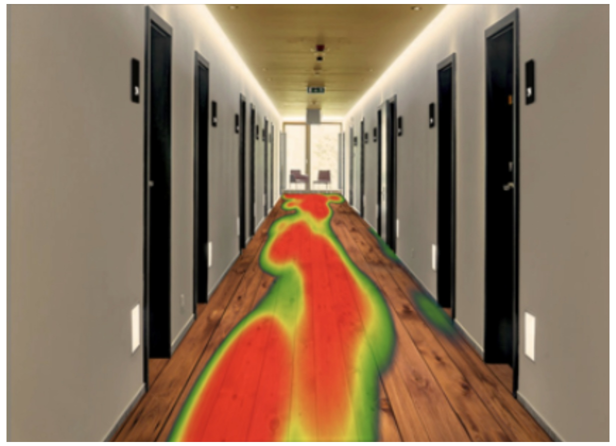


Figure 2.4: Heatmap for testing
navigational decision
(Albarrak et al., 2020)

Figure 2.5: Virtual characters
influencing navigation
(Yassin et al., 2021)

2.3.4 Atmosphere

Except for visualizing an information aspect of user behaviors, conveying the atmosphere of a place is valuable in augmenting social awareness. The atmosphere of a place significantly influences citizens' perceptions (Harispuru, 2012) and indirectly affects behavioral intentions (Dai & Zheng, 2021). Researchers have explored the concept of atmosphere by mapping various attributes (Quercia et al., 2014) and developing an "ambiance taxonomy" (Redi et al., 2018). In the digital realm, applications have been developed to evaluate atmosphere (Santani & Gatica-Perez, 2015; Santani et al., 2016) and use it to support the exploration of local vibes (McGookin & Brewster, 2012).

Despite our limited findings in the initial search, we further searched for works of visualizing emotions, considering that atmosphere can be understood as the emotions of places. Our exploration revealed that visualizations of emotions are applied to enhance VR experiences (Stellmacher et al., 2021), regulate users' states (Lorenzetti et al., 2018). In particular, Kepplinger et al., (2020) visualized user emotions in a similar fashion of space atmosphere to serve analyzing in-game user experience. However, we found no examples of actively using these kind of visualizations as cues for exploration. Therefore, incorporating visualizations that illustrate the atmosphere of a space into the study may lead to novel insights regarding fostering user exploration.

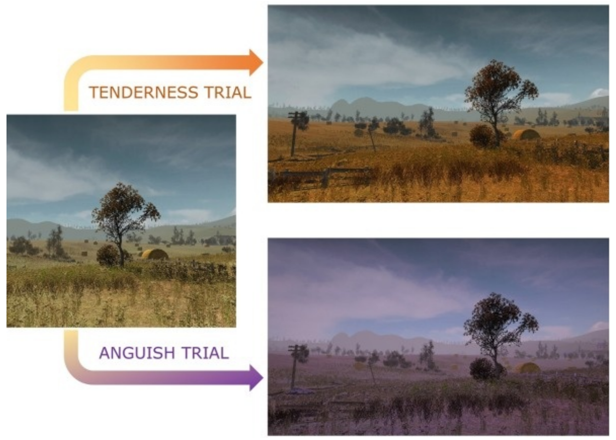


Figure 2.6: Attuning hues based on emotions (Lorenzetti et al., 2018)

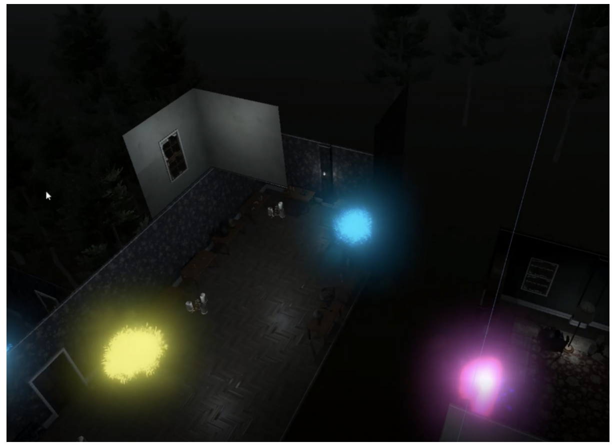


Figure 2.7: Representing emotions by color emission (Kepplinger et al., 2020)

2.5 Conclusion

Exploring techniques for illustrating usage scenarios of outdoor public spaces is often overlooked in current research on VR applications in urban design. Visualizing human traces as social cues provides opportunities to address this gap, benefitting the evaluation of outdoor public spaces. Based on the results of the pre-study interview, our study incorporated four types of trace visualizations. While these trace visualizations have been employed by researchers for analyzing human behaviors and navigational decisions, their potential impacts on users' explorative behaviors in VR outdoor environments remain unexplored. We anticipated that each type of trace visualization can elicit unique ways of exploration in VR outdoor environments due to their ability to signify distinctive aspects of user behaviors.

Chapter 3: Prototyping

Intro

This chapter introduces the prototyping processes of the VR system used for the experiment. To investigate the effect of each type of trace visualizations respectively, we need to build a research tool that allows displaying trace visualizations in multiple layers. The outcomes of pilot tests are discussed at the end, which leads to several points of improvement.

Overview

3.1 Technical Setup

This section covers the preparation of the VR environment and the trace visualizations, along with the used materials and techniques.

3.1.1 Preparing a Virtual Environment

The virtual environment used in the study should be able to support a variety of activities, allowing for various trace visualizations that fit the context of urban design. For these reasons, "Downtown West modular pack", a free asset released on UE marketplace by PurePolygons (2020), composed of benches, coffee shops, restaurants, a sandpit playground, food trucks, was selected for the study.

Unity version 2022.3.9f1 was used to enable the shopping street and trace visualizations prototypes. Universal Render Pipeline, a prebuilt Scriptable Render Pipeline, had to be adopted instead of Unity's built-in renderer to use the Shader graph function for building desired visualization effects.

Figure 3.1: the virtual shopping street

Line

The line visualization represents the pathways of previous users. The visualization was created by Shader Graph feature embedded in Unity. A gradient pink color and flowing effect were employed to convey the line's direction. To represent previous users' pathways, the lines are placed at a height lower than the user avatar's view. To inspire imaginations about the previous users' actions, most lines connect or go across multiple facilities

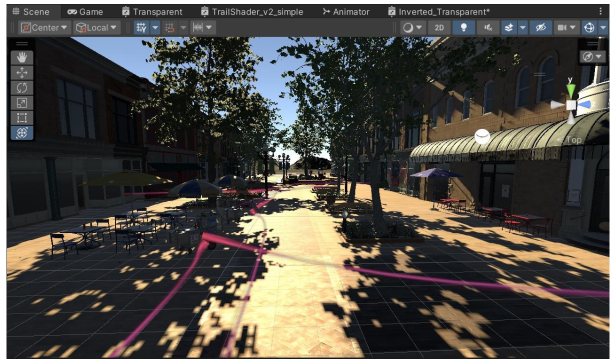


Figure 3.2: Line Visualization

Heatmap

The heatmap visualization indicates the length of staying time of previous users. The heatmap visualization was built by using "Volumetric Heatmap" (made by MichiGandi, 2023) and was later modified to support transparency editing. The area and the position of the heatmap are in accord with full-body motion.

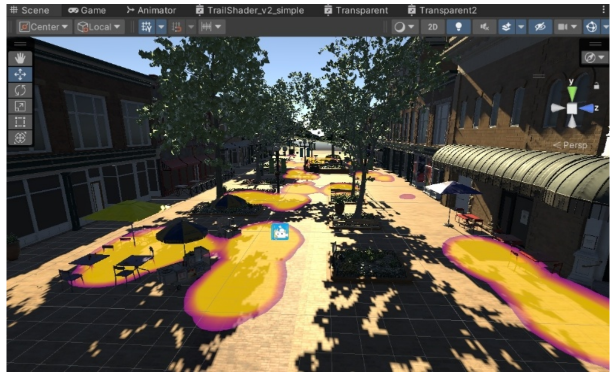


Figure 3.3: Heatmap Visualization

Full-body Motion

The human motion traces were created by using the rigged 3D models downloaded from Adobe Mixamo (www.mixamo.com), an online platform that provides free avatar models and animations. The transparency effect was produced by Shader Graph feature empowered by Unity.

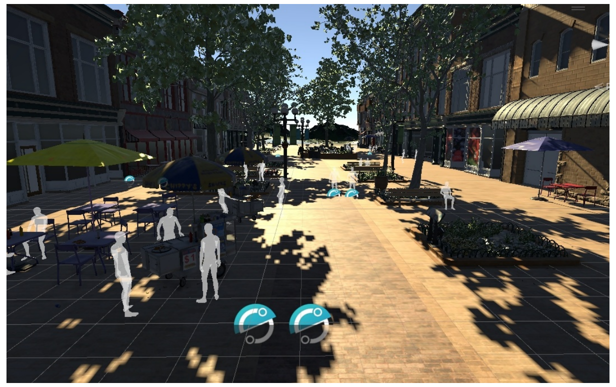


Figure 3.5: Full-body Motion Visualization

Bubble

The bubble visualization was built based on SlipinF's work (2019) on GitHub. Several changes in color, transparency, and flowing frequency were made to indicate different levels of social atmosphere intensity and reduce overall visual stimulation. To convey the intensity of atmosphere (exciting/quiet), two colors (red/white) were assigned to different bubbles, representing hot spots and relatively quiet places. A flowing effect with varied frequencies was also added to different bubbles to enhance the feeling of crowdedness.

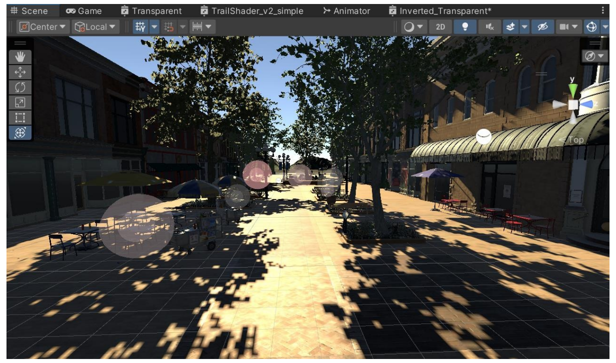


Figure 3.4: Bubble Visualization

Interface for modifying traces

To enable the second task, allowing participants to modify the visibility of the traces, an interface was created that contains four buttons for switching on/off the traces and four sliders that correspond to the transparency of each trace.

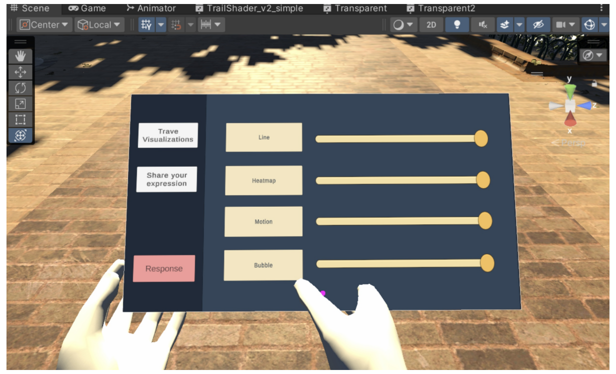


Figure 3.6: Interface

3.2 Pilot-testing

Pilot-testing was conducted with 5 participants in order to test the feasibility of the research tool, identifying aspects that need to be improved.

3.2.1 Procedures

Participants were asked to go through two sessions: 1) First, the participant observed each trace visualization and rated the extent to which the trace is useful and inspiring exploration; 2) In the second session, the participant was given a short context about finding the most desirable place to stay while waiting for a friend in the shopping street. During the process, all the traces were toggled on and the participant was able to modify their transparencies according to their expectation. A short interview was conducted after the testing session to identify the weak spots of the experiment set-up and protocol.

3.2.2 Iteration

Keep visualizations only in the central space

To increase the sense of immersion, several human models were assigned to enter the central space from the streets outside. The routes of these models were modified to be between different spots in the central space.

Participants were confused when observing lines that were extended beyond the central place of the shopping street as the line visualization needed to be aligned with several human motion traces that are around the entire scene. While inspiring curiosity for exploration, participants could not teleport out of the central space, which brought frustration.

Adjust the position of lines and heatmap

From a specific angle of view, the height of the lines and heatmap blocked a large area of users' eyesight, which was omitted during the prototyping process since the visualizations were arranged in a bird-eye perspective. As a result, the position of lines and the volume of heatmap emission were adjusted to make them closer to the floor visually.

Incorporate subjective ratings in the virtual environment

Participants considered it more appropriate to rate each trace visualization after all the tasks since it allows comparison between different visualizations when judging their usefulness and the level of granted inspiration. Further, by using the "Questionnair Toolkit" (version 1.2.0) made by Zefwih (2020), the rating forms were incorporated into the system to enable an uninterrupted experiment session (Figure 3.7).

Reframe the second task

The context of the second task did not sufficiently motivate exploration because the participants considered the trace visualizations as evidence of the past and would not affect how they stayed in the present moment.

All the participants mentioned that they would like to share their experiences and attitudes regarding spatial properties with other users who will experience the same space. Based on this outcome, the second task was reframed as "exploring the space, finding specific places that attract your attention, and expressing your feelings through assigning emojis".

To enable the second task, the feature of placing emojis was incorporated into the user interface. The feature was extracted from "VR 3D Menu - Concept UI Design" created by Epibyte (2020) and "3D Emojis Pack" by Basilic (2022) on Unity Asset Store with modifications. The feature allows users to place emojis onto specific spots, rotate, and change the size of the selected emoji (Figure 3.8).

Line - User pathway

*You can easily interpret the meaning of this trace visualization

○ Strongly disagree ○ Disagree ○ Somewhat disagree ○ neutral ○ Somewhat agree ○ Agree ○ Strongly agree

*You can easily acquire information from this visualization

○ Strongly disagree ○ Disagree ○ Somewhat disagree ○ neutral ○ Somewhat agree ○ Agree ○ Strongly agree

*You can get sufficient level of information from this visualizatio

Next

Figure 3.7: Rating form

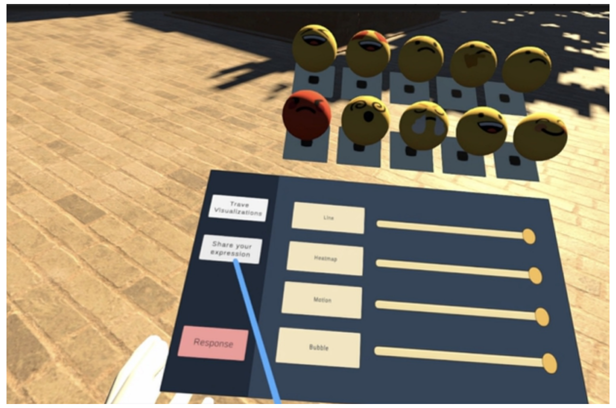


Figure 3.8: Interface for Assigning Emojis

3.3 Conclusion

To summarize, we selected a virtual shopping street as the environment for situating trace visualizations: Line, Heatmap, Full-body Motion, Bubble. These visualizations were developed using resources obtained from the Unity Store. Subsequently, we conducted pilot tests featuring two tasks: 1) articipants were asked to rate each trace visualization and 2) utilize them to pinpoint locations of interest based on their personal preferences. Findings from the pilot tests led to refinements, including adjustments to the positions of trace visualizations, integrating evaluation questionnaires into the VR environment, and reframing the second task as "evaluating the environment by assigning emojis." The next chapter will delve into the details of the user study process and the resulting findings.

Chapter 4: User Study

Intro

This chapter presents the procedures of the experiment sessions and the final prototype introduced in Chapter 3. The goal of the experiment is to investigate the explorative behaviors provoked by the display of trace visualizations, identifying potential exploration patterns and motivations. The experiment outcomes were analyzed with both quantitative and qualitative methods.

Overview

4.1 User Study Session

The experiment session was designed as a 1-hour exercise. Participants were asked to go through two tasks: Observation and Evaluation. Observation task focuses on inspecting single types of trace visualization and Evaluation task focuses on evaluating the space with the use of trace visualizations.

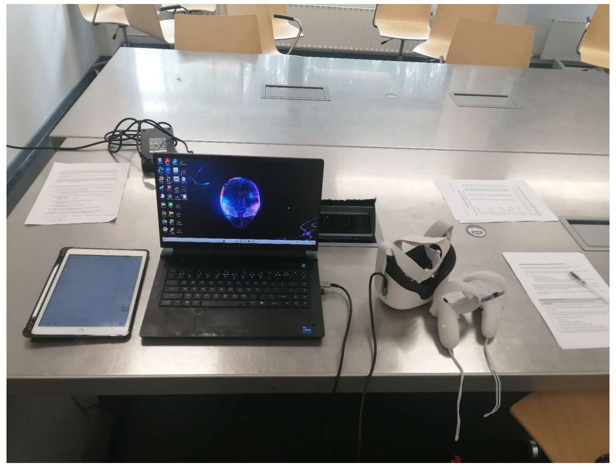


Figure 4.1: Study Set-up

Figure 4.2: Study session

Set-up

Due to the shortage of project rooms, evaluation sessions took place in different project rooms in the TU Library and the Faculty of Industrial Design Engineering. iFLYREC and WORD were used for recording and transcribing interview contents. The consent form was shared with the participants before the start.

Participants

20 participants were recruited through snowball sampling in the alumni network of TU Delft. Since in the context of public space design, the end users are usually ordinary citizens, the evaluation does not require the participants to have specific backgrounds or possess knowledge related to urban design. The participants were compensated with 10 euros after the session.

Participant No.	Gender	Age	Professional background	VR experience
P1	Female	24	Computer Science	Only a few times
P2	Female	27	UX Design	Only a few times
P3	Female	27	Ergonomics Research	Only a few times
P4	Female	25	Structural Engineering	Never used before
P5	Female	27	UX Research	More than 3 months
P6	Female	26	Strategic Design	Never used before
P7	Male	26	Strategic Design	More than 3 months
P8	Female	26	UX Design	Only a few times
P9	Female	25	UX Design	More than 1 months
P10	Female	24	UX Design	Only a few times
P11	Female	25	Water Management	Never used before
P12	Female	30	UX Design	Never used before
P13	Male	24	Traffic Engineering	Only a few times
P14	Female	25	Applied Mathmatics	Never used before
P15	Male	23	System & Control	Never used before
P16	Female	27	UX Design	Never used before
P17	Female	30	UX Design	More than 3 months
P18	Male	26	Industrial Design	More than 3 months
P19	Female	25	UX Design	Only a few times
P20	Female	26	Industrial Design	Only a few times

Table 4.1: Information of the participants

Procedure

The experiment process was separated into two sessions. Before the start, the participant was introduced to the topic of the research and was given instructions to familiarize the VR headset and controllers.

The first session is an "Observation" task. Participants was informed that they would observe four types of trace visualizations left by the previous users of the virtual space. The trace visualizations would be displayed one by one in a random order. During the observation, the participant could move freely in the space and was requested to think aloud, describing their experience regarding the perception of the trace visualizations and how that affected the way they explored the space. The duration of observing each trace visualization would be determined by the participant.

The second task is "Evaluation", with the aim is to understand how participants may actively use trace visualizations when evaluating the public space. Participants were given the context: "Imagine this is a shopping street designed for a location within 500m from your home. Your task is to explore the space, find places that attract your attention, and assign emojis to express your feelings by using the interface on your left hand".

All four types of trace visualizations would then be switched on and the participant was informed that they could make a preferred combination by turning on or off any visualizations or modifying their transparencies by using the interface on the left-hand controller.

Figure 4.3: Evaluation task

Measurement

Before and after the study session, participants filled in Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993). After completing two sessions, the participant rated for each trace visualization in the VR setting. Lastly, participants removed the headset and filled in Igroup Presence Questionnaire (IPQ)

In this project, trace visualizations are implemented as a means of influencing users' explorative behaviors, and thus, they can be seen as visual cues that support and foster exploration, the questionnaire for evaluating visual cues proposed by Wallner and Kriglstein (2016) is applicable in evaluating the trace visualizations:

Items	Meanings
Clarity	To what extent the trace visualization is easily interpretable
Ease of Extraction	To what extent it is easy to extract information from the trace visualization
Informativeness	How much information you can gather from this trace visualization
Inspiring	To what extent the trace visualization inspire you to explore more in the space
Usefulness	To what extent the trace visualization is useful in supporting finding places of interest
Aesthetic appeal	To what extent does the trace visualization distract you from immersion in the space
Distraction	To what extent the trace visualization is aesthetically pleasing

Table 4.2: Items for evaluating trace visualizations

We removed items “Readability” and “Accurateness” that originally used in Wallner and Kriglstein’s work (2016) and added new items, “Inspiring” and “Distraction”:

“Readability” indicates how difficult users are able to discern different visual elements. In this study, each trace visualization emphasizes a specific type of information, which makes them very distinguishable from each other.

“Accurateness” indicates the extent to which the visual element presents the correct information. Since different trace visualizations reveal different information, there is no unified standard for adopting this item.

“Inspiring” is added to evaluate to what extent participants are motivated to explore.

“Distraction” is added to evaluate whether trace visualizations hinder participants from immersively experiencing the space

Interview

After a short break, the participant was invited to have a semi-structured interview. The interview questions focused on investigating how the participants perceived each type of traces visualization and how it affected the participant’s exploration in the virtual shopping street. The participant also answered about how they created the combination of trace visualizations and the reason behind the arrangement. The closing questions elicited participants’ speculation regarding what other types of traces they want to experience or create by themselves.

Data collection

Before: The consent form, SSQ (Simulator Sickness Questionnaire), and general demographic information of the participants were collected before the session.

During: Participants’ verbal expression was recorded; Participants’ subjective ratings in a 7-points Likert-scale for each trace visualization were collected at the end of the session.

After: Participants filled in the second SSQ and IPQ (Igroup Presence Questionnaire). The interview was recorded and transcribed right after the session.

4.2 Quantitative Results

To understand how the visualizations of human traces are used in the processes of public space design, and urban designers’ opinions regarding how they can be used in supporting the evaluation of outdoor public spaces. We carried out interviews with 6 participants who have urban design experience.

4.2.1 Igroup Presence Questionnaire (IPQ)

The result of Igroup Presence Questionnaire is presented in Table X. IPQ is used to measure general presence and three subscales: spatial presence, involvement, and experienced realism. The virtual shopping street employed in this study provides a level of general presence (m = 1.9), while the experienced realism remains in a low level (m = -0.275).

Subclass	Mean	SD
Ease of Extraction	1.9	1.021
Informativeness	0.99	1.732
Inspiring	0.637	1.752
Usefulness	-0.275	1.676

Table 4.3: IPQ result

4.2.2 Adopted Measurement for Trace Visualizations

Items regarding the trace visualizations (Clarity, Ease of Information Extraction, Informativeness, Inspiring, Usefulness, Aesthetics, Distraction) were measured on 7-point Likert scale (left: Fully disagree; right: Fully agree).

Perception of The Trace Visualizations: Clarity, Ease of Extraction, Informativeness

Since the three items, Clarity, Ease of Extraction, Informativeness are associated with the overall perception of a trace visualization, it provides a better understanding to view the results of these items together.

As shown in Figure 4.2, unsurprisingly, full-body motion trace is most easily interpretable (“Clarity”: M = 6.578, SD = 0.507) and clearly exceeds other three types of visualizations in conveying information (Ease of Extraction: M = 6.421, SD = 0.692; Informativeness: M = 6, SD = 0.816), as it contains more detailed information and is presented in a way that is similar to the real world context. It can be reasonably assumed that the relatively low degree of clarity associated with the heatmap (M = 4.315, SD = 1.454) and the bubble visualizations (M = 3.842, SD = 1.537) is induced because the two visualizations are open for a variety of interpretations, while the line visualization (M = 4.684, SD = 1.765) is relatively easier to recognize as it is commonly used for indicating pathways of users.

The line and the heatmap visualizations allow an easy extraction of information to a close extent (Line: M = 4.684, SD = 1.668; Heatmap: M = 4.684, SD = 1.454).

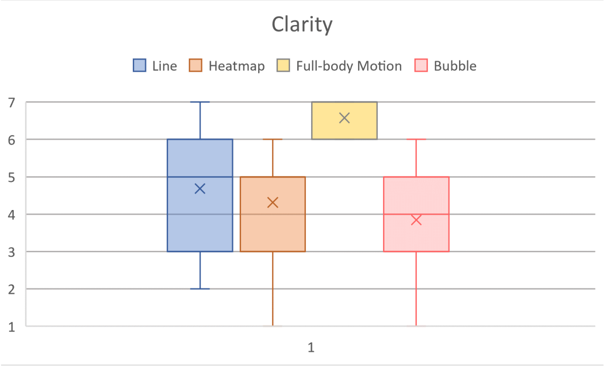


Figure 4.2: Degree of Clarity

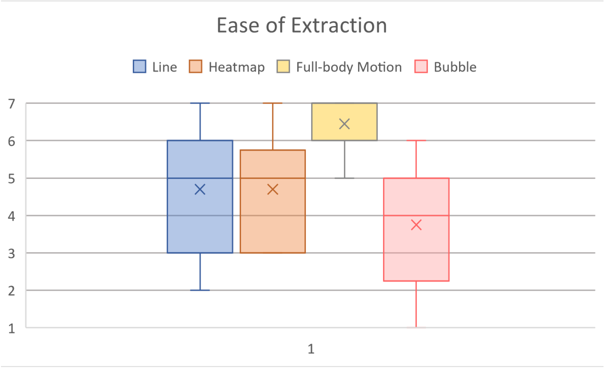


Figure 4.3: Degree of Ease of Extraction

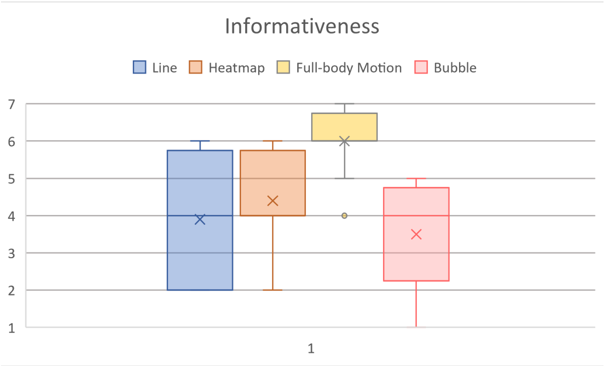


Figure 4.4: Degree of Informativeness

But, heatmap gains an overall higher degree of information richness (M = 4.421, SD = 1.304) compared to the line (M = 3.894, SD = 1.663). The bubble visualization receives low rates in both Ease of Extraction (M = 3.736, SD = 1.446) and Informativeness (M = 3.473, SD = 1.263).

Impacts on Exploration: Inspiring and Usefulness

The item “Inspiring” and “Usefulness” describe to what extent a trace visualization encourage exploration and whether it is actually helpful for users to locate spots they are interested in.

As indicated in Figure 4.5 and 4.6, full-body motion trace provides the strongest effects in encouraging exploration (M = 6.157, SD = 1.302) and is seen as the major factor for identifying points of interest (Usefulness: M = 6, SD = 0.816). While the line (M = 4.736, SD = 1.367) and the bubble visualizations (M = 4.315, SD = 1.529) are less inspiring compared to the heatmap (M = 4.684, SD = 1.416), all three visualizations are considered useful for facilitating the discovery of points of interest to a certain extent (Line: M = 4.315, SD = 1.6; Heatmap: M = 4.368, SD = 1.535; Bubble: M = 4.263, SD = 1.446). Additionally, the relatively low degree of inspiring effect associated with the bubble visualization can be explained by its low level of clarity and informativeness.

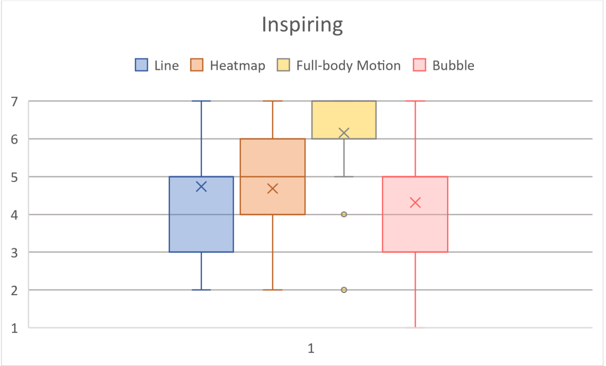


Figure 4.5: Degree of Inspiring

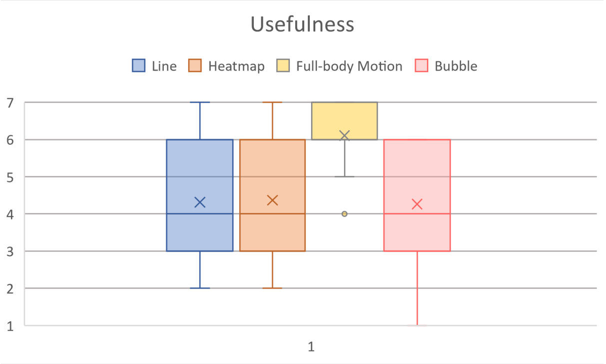


Figure 4.6: Degree of Usefulness

Aesthetic Appeal

As demonstrated in Figure 4.7, full-body motion (M = 5.526, SD = 1.348) exceeds in aesthetic appeal. Compared to the line (M = 5.052, SD = 1.508), the heatmap (M = 4.157, SD = 0.898) is less aesthetically pleasing. Lastly, the opinions regarding the aesthetic level of the bubble (M = 4.315, SD = 1.6) is quite diverse, which might be related to diverse interpretations.

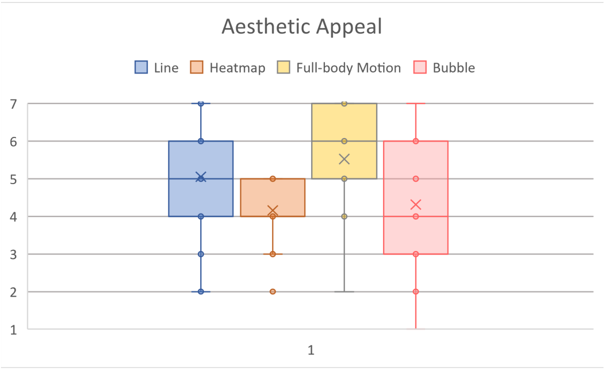


Figure 4.7: Degree of Aesthetics

Distraction Level

As shown in Figure 4.8, the line (M = 3.263, SD = 1.284) and the full-body motion (M = 3.105, SD = 1.911) visualizations are less distracted during the exploration, which might be induced by the fact that the position of lines is lower than users’ eyesight and it does not occupy large visual area, and the full-body motion is similar to the real world experience. On the contrary, the heatmap (M = 4.631, SD = 1.382) and the bubble (M = 5, SD = 1.333) visualizations create most distraction as they cover a large proportion of one’s visual area.

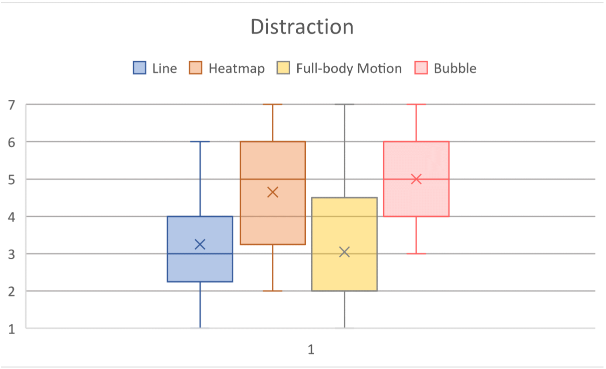


Figure 4.7: Degree of Aesthetics

4.3 Qualitative Results

This section presents the qualitative outcomes derived from both video analysis and thematic examination of participants' responses during the interview session.
Initially, we reviewed participants' actions in the recorded videos, identifying and categorizing various explorative behaviors such as direct movement, pausing to select a path, and stopping to look around. From participants' reactions during exploration, we derived distinct themes to classify explorative behaviors motivated by similar factors.
Moreover, participants' interview responses were transcribed for thematic analysis. Quotations reflecting participants' perceptions of traces and explorative behaviors were grouped into four categories: Line, Heatmap, Full-body Motion, and Bubble. Subsequently, we organized these quotes into two overarching themes, namely "Perception" and "Exploration Decisions," further clustering them to frame sub-themes representing diverse perceptions of trace visualizations and decisions related to participants' exploration of the VR environment under the influence of trace visualizations.

Finally, we validated the explorative behavior themes by comparing them with the findings from "Perception" and "Exploration Decisions." Consequently, we identified five major exploration patterns: 1) Direct Movement: participants directly approach a specific trace; 2) Stopping to Look Around: participants stop moving and take a look around the overall environment before moving to next position; 3) Observing While Moving: participants observe traces and the environment while moving, without intentionally approaching the traces encountered along the way; 4) Orderly Exploration: participants navigate according to the space structure and stop moving to observe traces encountered along the way; 5) Avoid Approaching: participants intentionally avoid getting close to the visualization. Each trace visualization evoked distinct exploration patterns.

The subsequent section will initially present overarching findings regarding the overall impact of trace visualizations and then delve into participants' explorative patterns associated with each type of trace visualization. Findings regarding participants' perceptions of trace visualizations will be presented in connection to their relevance to specific exploration patterns.

4.3.1 General Findings

Trace Visualizations Facilitate The Discovery of Unnoticed Places

In general, the presence of trace visualizations facilitates the participants to discover places that they did not notice before seeing the visualizations. In particular, full-body motion trace was reported (P4, P7, P9, P17, P18, P20) to have a strong effect in attracting attention to unnoticed places or objects: "*The human motion, especially, kind of makes me observe it differently. Because then I see what they're doing there and if like in a real world, you can imagine this in the sense that if it was an empty street, I would not kind of be like, for example, I would not be in front of the sale building unless there is something happening there*" (P20). However, it was also reported (P3, P6, P9, P14, P15, P16, P17, P18, P19) that the mixture of four visualizations caused information overload: "*It's just like in the real world, you don't want to be surrounded by too many advertisements because it will let you feel very noisy in this environment. You still want to keep certain appropriate guidelines, but you still want to have some kind of a space to explore, instead of being fully guided and affected*" (P17).

Mixing trace visualizations attract more attention but increase visual burden

In the "Evaluation" task, all four types of trace visualizations were turned on as the initial setting. A number of participants (P4, P5, P8, P9, P13, P18, P19) were attracted by the places where multiple visualizations intersected: "*Yeah, it does. It does a lot. I think the more intense the visualization are, I think the visualizations do a good job of getting my attention*" (P18);

The presence of trace visualizations makes users more aware of empty spaces

Displaying the trace visualizations not only provides visual focus for exploration but also raises the participants' awareness of empty spaces. Participants may be attracted by empty places because of personal preferences to quiet places, or curiosities indirectly induced by trace visualizations: "*I always try to find places that aren't walked before or like maybe. So probably would avoid those images. I see other people I would go, just explore where they haven't been*" (P12).

4.3.2 Exploration Patterns: Line

All the participants recognized the line visualization as the pathways of previous users. However, 3 participants (P10, P13, P17) recognized the lines as decorations at first. Additionally, the visual elements of the lines reminded 2 participants (P12, P16) about laser protection lines. We identified three exploration patterns which are driven by various user perceptions respectively.

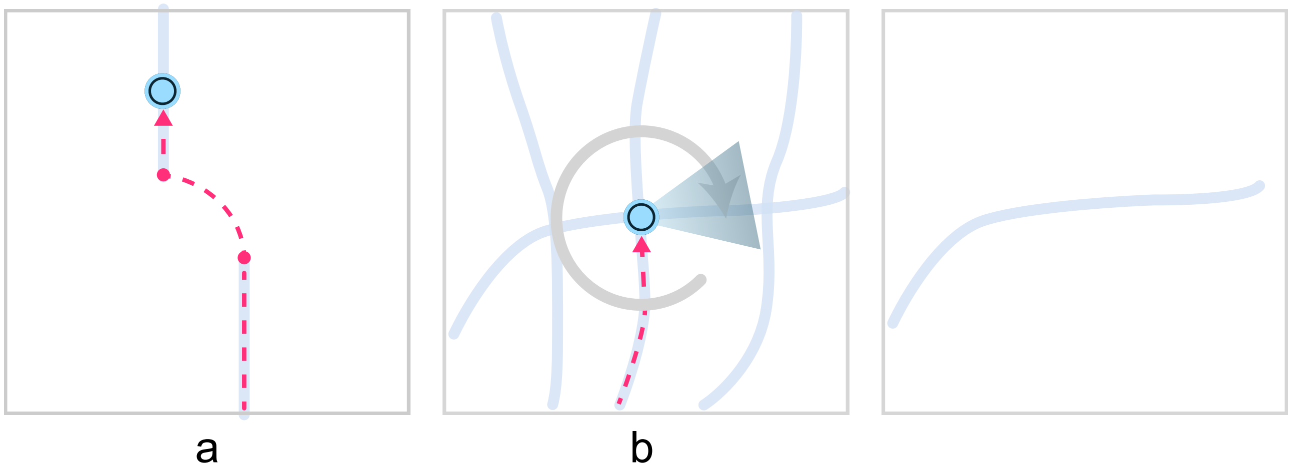


Figure 4.9: Patterns - Line
(A: Observing while moving; B: Stopping to Look Around; C: Direct Movement)

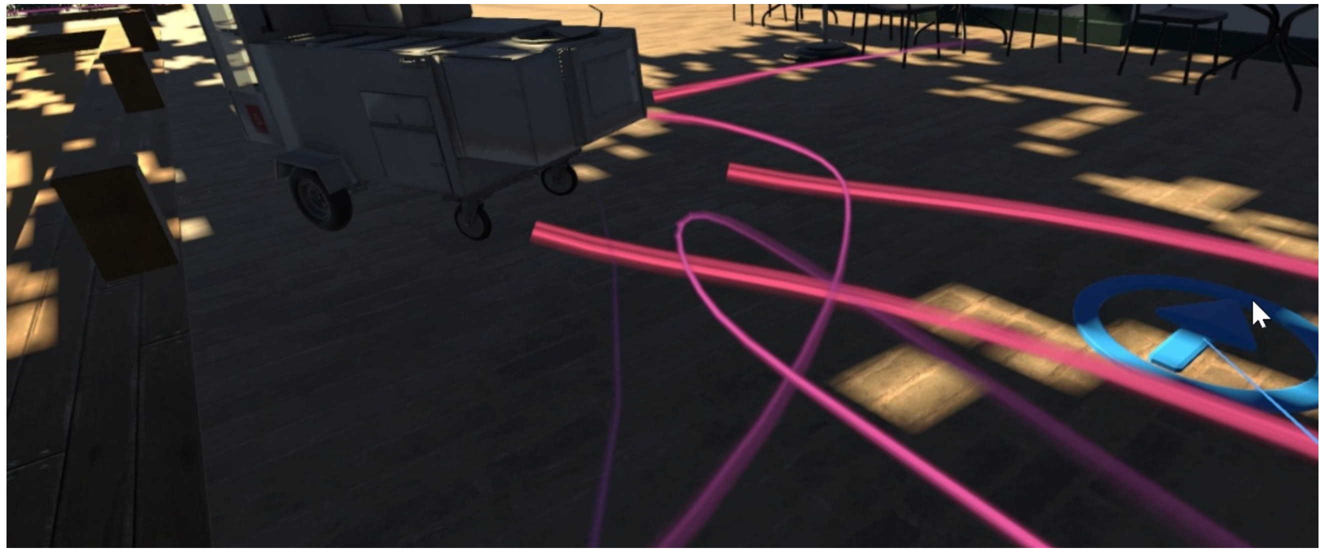


Figure 4.9: Line Visualization

Pattern 1 - Observing While Moving: Following and jumping between lines

In the "Observation" task, a total of 12 participants (P1, P6, P7, P8, P10, P11, P13, P14, P15, P16, P18, P19) naturally followed the lines and adopted the pattern "Observing While Moving". Notably, 6 participants (P6, P7, P14, P16, P18, P19) exhibited a tendency to continue exploration by transitioning between lines. When approaching the end of a line, participants promptly assessed their interests in the end point. If uninterested, participants directly jumped to and follow a neighboring line, as exemplified by one participant: "Like at some point it just like doesn't matter like where this line end up or if it ends at all because I can just like go jump to another line and explore the other one" (P7). This following behavior suggests a focus on "exploring along the way" rather than fixating on what lies at the end of the lines.

The frequent jumping between different lines can be attributed to the perception that **the line visualization lacked focal points**. Unlike the other three types of trace visualizations, participants (P4, P7, P9, P10, P14, P15, P16, P19) expressed an interest in exploring their surroundings throughout the entire process when following the lines, rather than solely focusing on the end points. Consequently, jumping to another line was experienced as a continuous process rather than segmenting the entire exploration into multiple journeys.

Some participants (P4, P7, P10, P14, P19) perceived this feature in a positive way: "*It kind of offers you a path to go through it, but without guiding you too much...without interpreting like which way you should go so that gaining a degree of freedom*" (P19). Nevertheless, this feature also weakened the passion for exploration of a few participants (P5): "*Like this line going from this area to the other side, but I cannot see the end of the line, also not the starting point in my area. So I don't know what it means to me*" (P5).

While the majority of the participants (12 out of 20) tended to follow lines, 6 participants (P5, P6, P7, P8, P9, P10) found it difficult due to misinterpreting a single line as multiple different parallels when teleporting.

The line visualization was composed of a gradient color and a flowing effect to signify directions. However, **moving by teleportation seems to disrupt the continuity of the users' perception of the line** (Figure 4.10). After teleporting to a new location, participants established a fresh understanding of the line, distinguishing it from their perceptions made before teleportation. For instance, P10 mentioned that she initially followed a purple line and only found a pink line on the floor after teleporting forward, leading to confusion about the number of line types in the space and the conveyed information.

Figure 4.10: Misperception of the line

Due to teleportation-induced disruptions, 11 participants (P3, P5, P6, P7, P9, P11, P14, P16, P17, P19, P20) were unable to discern the directions of the lines. Since the perception of a line is segmented by the viewpoints projected from each standing spot, some participants failed to notice the gradient color: "*Because the line one I have confusion is just the direction. You know, I feel like if it has a color like gradient color for example like flowing from one end to another one like electricity then I can just follow it*" (P19).

Among this group, 5 participants (P3, P5, P6, P9, P17) noted that the unclear direction negatively impacted their willingness to follow: "*I don't know how to interact with it. Except for observing, I don't think it provides much indication because there is no direction*" (P9), but the rest did not consider showing the direction as an essential factor: "*Why does it even matters? We don't have to walk from a specific place to another place*" (P11); "*Although I cannot really tell the beginning or the end, but I do find it interesting to just follow the lines and to explore from the beginning to the end or the other way around*" (P7).

* * *

Few lines traversed the sandpit and the bridge in the virtual shopping street. Due to the the constraint that the models of the sandpit and bridge were packed, participants could not teleport onto them. This limitation led to frustrations when participants (P12, P17) failed to follow lines crossing these areas: "*To a certain extent, it has navigational effects. So when I saw trails going there, I felt the place was supposed to be walkable for me*" (P17).

Pattern 2 - Stopping to Look Around: Observing traversing lines

9 participants frequently paused to examine their surroundings while following lines. When there were other lines intersecting the pathway the participant was following, participants tended to compare the directions of the traversing lines and inspect the environmental context: "*So like I'm moving on a line and to a point it diverges into different paths. Then I [my attention] diverge too*" (P4).

* * *

One reason for this pattern is the intention to identify the density of lines. 6 participants (P7, P8, P11, P13, P18, P19) mentioned that **a high density of lines attracts more attention**, as it implies increased human activities and allows for an active evaluation of the popularity of nearby shops based on the line density. Conversely, **areas with fewer lines also attracted attention**, as participants speculated about potential uncommon activities happening in those areas.

Pattern 3 - Direct Movement: Towards the end points

6 participants (P8, P13, P15, P16, P18, P20) closely examined the trails of lines and sought the endpoints of the lines before moving. Although all 6 participants followed lines before reaching the endpoints, it was evident that they intentionally approached the endpoints and did not redirect during the process.

* * *

5 participants (P3, P5, P6, P16, P19) affirmed that **being able to see the endpoints directly from their standing position affected their passion for exploration**. Since the expectation of discovering novel places drives exploration, being able to see the context at the end of a line directly did not trigger curiosity for further exploration. On the contrary, not knowing the end point at first place fueled exploration by following lines: "*Honestly, it doesn't make so much sense when it's in the space that I already know. It's like something I can easily see, but then I think it triggers my curiosity when I think there's something I'm missing or there's like a hidden spot for those kind of things*" (P16).

* * *

To clarify, in some situations, participants did approach the endpoint of a line when they could observe it directly. Eight participants navigated through the virtual shopping street by locating points of interest (e.g., food truck, sandpit, benches, etc.). They moved directly towards the points of interest and deciphering the information unfolded by all the lines connected to that spots: "*I mentioned that that was something more likely interest to me in the sense that I'm not going to determine where I go with that. Yeah, but I will just be very curious to see how other people move around*" (P20). But this behavior was not motivated by the visualization but the personal curiosity of the elements presented at the end point.

4.3.3 Exploration Patterns: Heatmap

Heatmap receives a low rate of clarity (see section 4.2). Participants (P2, P4, P6, P7, P8, P12, P16, P18) found it better to interpret the heatmap with the presence of other viualizations. Most participants perceived it as the density of the previous users, while only a few participants (P3, P14) believed it to be the length of staying time.

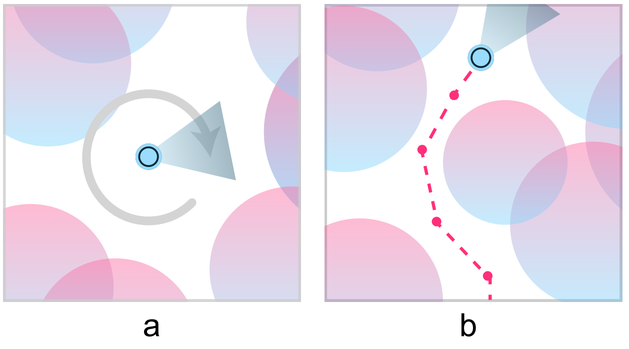


Figure 4.11: Patterns - Heatmap
(A: Stopping to Look Around; B: Avoid Approaching)

Pattern 1 - Stopping to Look Around: Comparing the heatmap pieces

In the presence of the heatmap, 15 participants frequently paused to compare different sections of the heatmap before moving to the next position. This behavior was motivated by the limitation of the first-person view, which hinders participants to obtain a comprehensive view of the entire heatmap: "*I did see it from a distance, but it doesn't give me that much information and I look at it from far away because I can't see the gradient*" (P18).

This frequent comparing behavior can be attributed to the fact that **large areas of heatmap make it less self-explanatory**. The heatmap visualization was made based on the positions of the full-body motion traces, covering extensive areas of the virtual shopping street. Participants (P2, P3, P5, P6, P11, P14, P19) found the heatmap less indicative and self-explanatory under this condition: "*Heatmap makes me a bit confused because of its proportion. It covers 70 - 80% of the space and I feel like it is not as indicative as the line*" (P19). This setting negatively influenced the passion for exploration since participants perceived multiple places as similarly important.

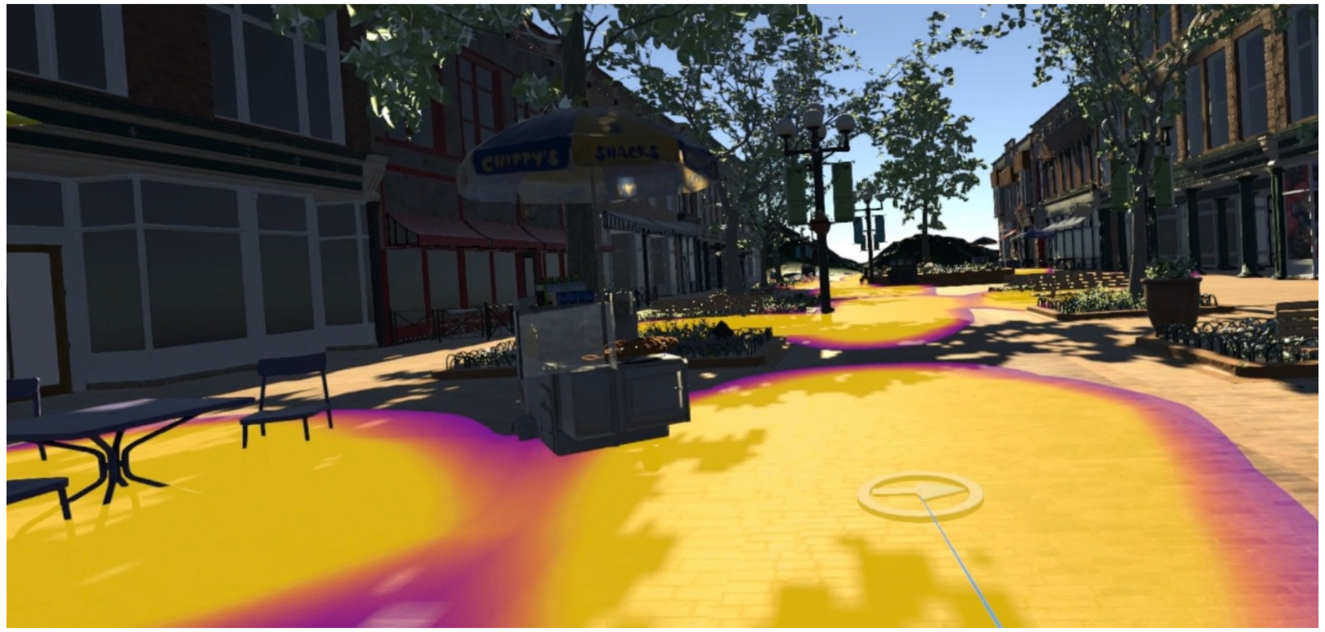


Figure 4.12: Heatmap Visualization

Pattern 2 - Avoid Approaching: Avoid stepping into the heatmap

Although not explicitly demonstrated in the exploration process, 7 participants expressed the intention to actively avoid the heatmap. Participants might teleport onto empty spots or only step onto the edge of the heatmap.

This pattern was induced because **the heatmap is inconsistent with the materials in the space**. 5 participants (P11, P16, P18, P19, P20) reported the heatmap to be oversaturated, making it difficult to recognize the textures beneath and increasing perceived distraction: "*...because the heat map, the colors are quite saturated. So it also kind of distracts me from experiencing the space, so I also lowered the transparency*" (P8). **The color of the heatmap also prompted associations with high temperature or materials**, such as lava (P4, P7, P9, P10, P16, P20), fostering an assumption that the heatmap signified warning areas. Moreover, since the heatmap conflicted with the textures in the VR environment, it **overly attracted participants' attention** to itself rather than the environment: "*This way [reducing transparency], I feel it is more integrated into the world and makes me not just looking at the visualization itself*" (P5). Stepping into this "inconsistent material" may also reduce the level of immersion: "*Maybe it's too bright, make me feel like I'm stepping onto a substance that is different to the floor*" (P9).

4.3.4 Exploration Patterns: Full-body motion

As full-body motion traces represent user behaviors realistically, they were well-perceived by all participants. However, the difference in transparency was not consistently noticed. This lack of perception could be attributed to the fact that the perceived transparency level was influenced by the lighting conditions of the environment. A transparent full-body motion trace looks lighter in sunny areas while becoming more visible in shadowy areas: "*If all these things' transparency can be adjust by AI system based on the light in the virtual realities, maybe in the night or in the morning I think it will help a lot*" (P17).

We identified four exploration patterns related to full-body motion visualization and two major findings about user perceptions.

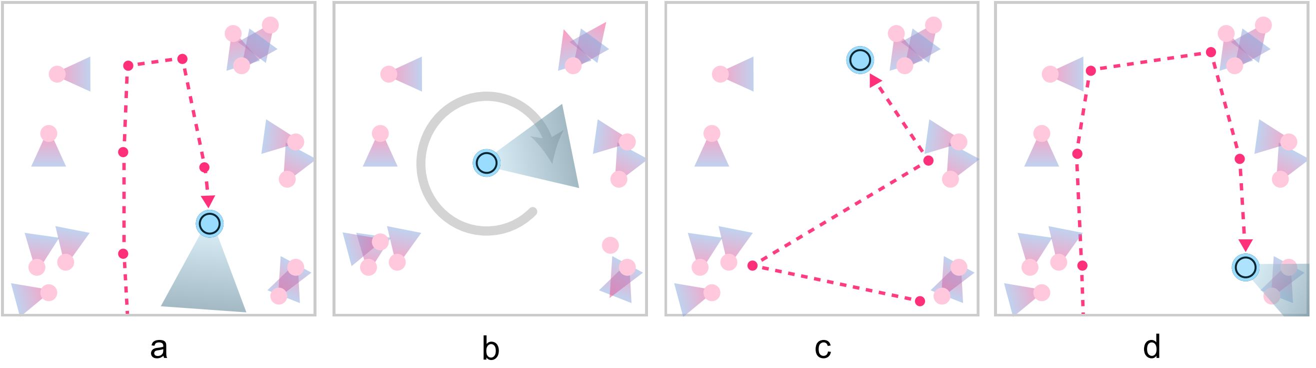


Figure 4.13: Patterns - Full-body Motion
(A: Observing while moving; B: Stopping to Look Around; C: Direct Movement; D: Orderly Exploration)

Figure 4.14: Full-body Motion Visualization

Pattern 1 - Observing While Moving

7 participants were found to make quick observations while moving. Rather than specifically approaching 3D characters, they swiftly examined the characters' actions and moved forward, indicating a natural exploration approach akin to travelers in the real world.

Pattern 2 - Stopping to Look Around: Examining the atmosphere

9 participants frequently stopped to examine the overall environment. This behavior aimed not only to understand the global atmosphere but also to identify gathering places. This was further corroborated by 11 participants (P2, P3, P4, P5, P7, P8, P14, P15, P16, P17, P19) who stated that the density of 3D characters attracted their attention.

Demonstrated by Pattern 1 and 2, participants explicitly evaluated the ambiance of the virtual shopping street, which was encouraged by the fact that **the full-body motion visualization enhanced participants' empathy** for evaluating the space usage and inspired more imagination about usage scenarios. For instance, participants can easily receive the ambiance of the space: "*The singer or like some people cheering, I just put a positive emoji their overall because I think it's they're showing good vibe and it's quite interesting to see*" (P16). Within the ambiance brought by the full-body motion visualization, participants may immerse themselves into the role of the characters in the space: "*I feel that human feel, not me, because I'm trying to imagine what his emotion at the moment and what if I'm there, and if I feel like the same thing*" (P6). Interestingly, even in the virtual shopping street without embedded sounds, participants (P4, P7) expressed concerns about the "noises in crowded areas may affect them" only when observing full-body motion visualization, even though they could similarly recognize the density of previous users by observing line and heatmap visualizations.

Pattern 3 - Direct Movement: Towards the traces

8 participants preferred directly teleporting to the full-body motion trace they were interested in, conducting extensive observation of each surrounding trace and virtual object in close proximity. When there were no traces presented in a close range, participants navigated based on space structures. For instance, participants moved towards unexplored areas and reapplied the "Direct Movement" pattern when reaching an area containing rich motion traces: "*I actually want to be close as possible I want to know what they're doing. That's interesting. Especially for the motion*" (P7).

Pattern 4 - Orderly Exploration

6 participants explored by following the space structure. Each time participants encountered a 3D character, they paused and examined its motion: "*If you start with the heat map, you probably could figure out like, OK, these are the important places. Yeah, but the people part it's you have to just go through each of them*" (P15).

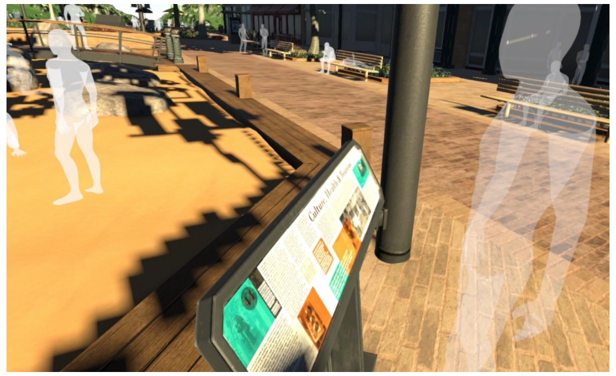


Figure 4.15: Participants noticed the advertisement board due to the full-body motion

With pattern 3 and 4, participants expressed a clear interest in observing detailed actions of 3D characters, supported by the finding: **participants were attracted more by the actions of 3D characters and the objects they were interacting with.** 12 participants (P1, P5, P6, P7, P8, P10, P11, P14, P15, P16, P17, P20) observed full-body motion traces at a very close distance, and a couple of participants noticed virtual objects they had missed before (e.g., advertisements) (Figure 4.13). These behaviors suggested participants paid more attention to the behaviors of 3D characters and the objects they interacted with: "*I would follow this kind of guidance like a line or heatmap, but for more detailed things like the real sign or read advertisements, I think the motions the motion visualization helps me more*" (P17). While the full-body motion visualization has the strongest effect on inspiring exploration (see section 4.2), it is worth mentioning that deploying full-body motion traces can also disturb the observation of the space: "*For the scenario when there are a lot of people, I just want to join them. So actually it's different. I want to see how it feels like in that spot, but like too much focus on human interactions rather than the scenery*" (P19).

4.3.5 Exploration Patterns: Bubble

The interpretations of the bubbles varied between the participants. Most participants perceived the bubbles as hot spots which represent the gathering places where most social activities had occurred. 2 participants (P7, P9) associated the bubbles with sounds, which is likely due to the fact that they observed the bubbles right after seeing full-body motion traces. Only P4 assumed the bubbles represented the frequency of human activities, which is also highly related to full-body motion traces.

Three distinct exploration patterns emerged, revealing polarized opinions about the bubble visualization. A number of participants directly approached the bubbles, while others tended to avoid them.

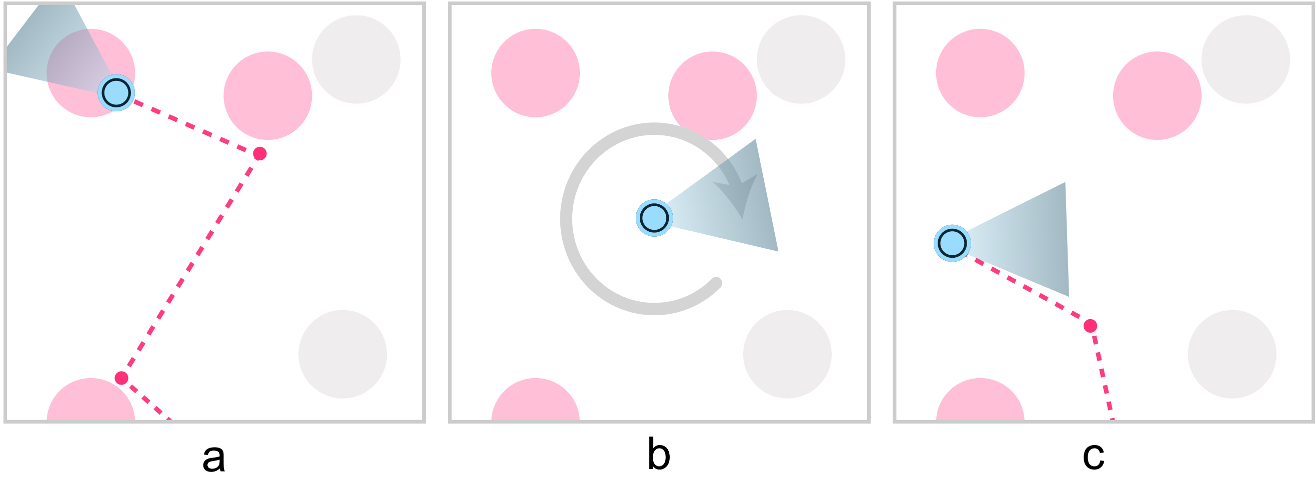


Figure 4.16: Patterns - Bubble
(A: Direct Movement; B: Stopping to Look Around; C: Avoid Approaching)

Pattern 1 - Direct Movement: Towards Bubbles

7 participants (P2, P8, P10, P15, P16, P18, P20) had a clear intention to approach the bubbles directly, which is likely related to the attraction of the visualization itself. As mentioned above, participants can easily associate the bubble visualization with positive emotions or vibes, which ignites the passion for interacting with the bubbles: "I think the bubbles, first I thought they were really fun. So I just wanted to get close to one of them and try to interact with it" (P16). The flowing effect may also contribute to this exploration pattern as it makes the bubbles looked interactable (P10, P16, P19): "*But it's also a little disappointing me that I can't really interact with these bubbles like because I have the feeling if I poke them and they can do something*" (P16).

The attraction of the bubble visualization was induced because **it can be easily associated with social activities**. While participants generated diverse interpretations of the bubbles, all seemed to emphasize the level of space vitality or the intensity of positive emotions within specific places: five participants (P5, P6, P15, P16, P19) reported feeling a sense of happiness when observing the bubbles, and the variation in colors was perceived as the level of activity in the area (P7, P10, P11). Specifically, P6 assumed the bubbles to represent the heartbeats of users in each location, implying the intensity of excitement.

Nevertheless, as articulated by a few participants (P10, P16), they were more captivated by the bubble visualization itself than the environment, potentially disrupting their exploration of the space: "*But then I feel like I focus a lot on the bubbles and I'm not really focusing on this space, exploring this space. I'm just poking these bubbles and see if I can get into them*" (P16).

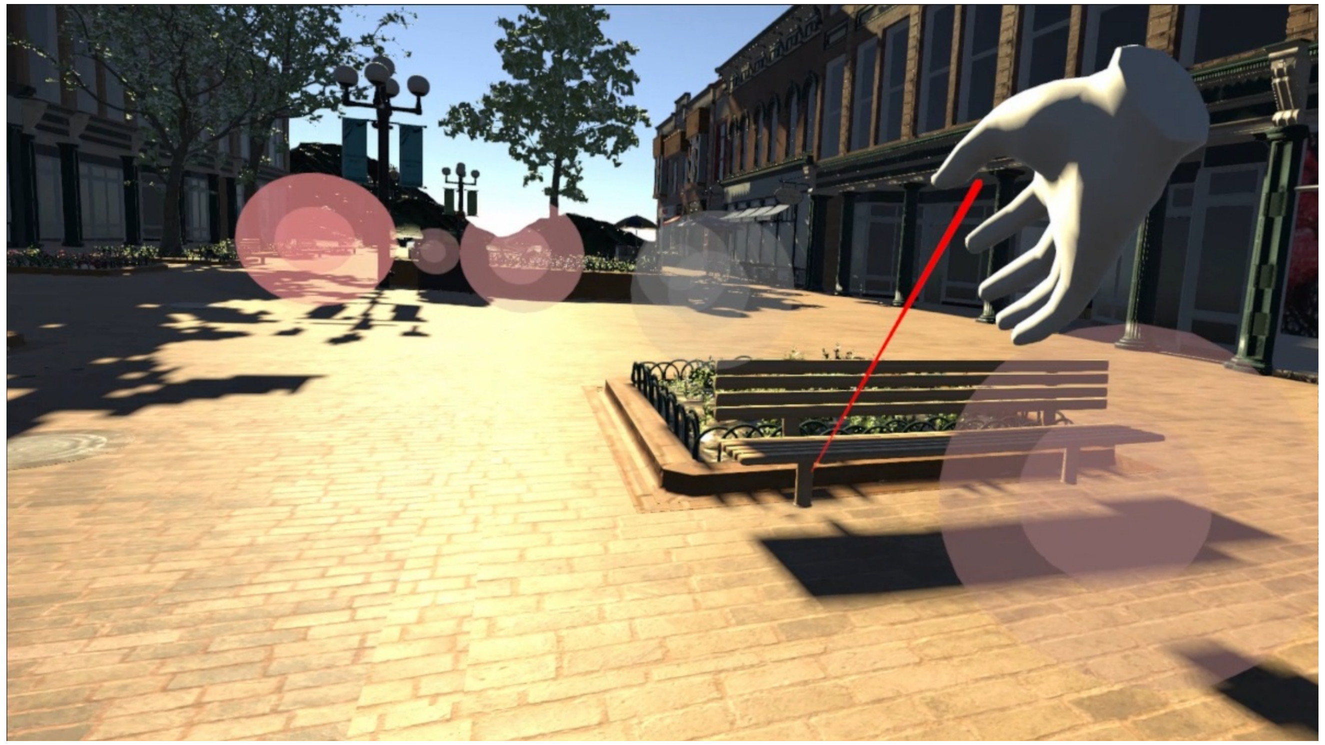


Figure 4.17: Bubble Visualization

Pattern 2 - Stopping to Look Around

12 participants (P2, P3, P4, P5, P6, P11, P12, P13, P15, P17, P18, P19) frequently stopped moving and observed multiple bubbles. This patten was likely due to the fact that participants were trying to decipher the meaning of the visualization through comparing different bubbles, which can be supported by the low rate of clarity it received.

The bubble visualization consists of multiple elements (size, color, the flowing frequency) which causes confusion. Participants (P3, P5, P6, P7, P8, P10, P12, P13, P18, P19) tended to understand the meaning of the visualization by interpreting each element separately, and thus, assuming that multiple visual elements may indicate different information: "*The bubble, I find it hard to interpret it because it has a different color and the size might different as well and it moves a little bit like glowing*" (P3).

Pattern 3 - Avoid Approaching

Unsurprisingly, because it is relatively difficult to interpret the bubble visualization, some participants (P4, P6, P8, P18, P19, P20) intentionally avoided approaching the bubbles. Moreover, the visual elements of the bubbles is another distinctive reason for the avoidance behaviors.

10 participants (P2, P6, P7, P8, P9, P11, P12, P15, P17, P18) stated that **the bubble visualization clearly caused distractions**, which is associated with three factors: 1) The size of the bubbles is too large. When approaching, the bubbles occupied a large proportion of participants' visual areas: "Because they're there, no matter where I stand, I can always see them. So it just occupies a large amount of my visual space" (P8). With the flowing effect, participants felt the presence of the bubbles was "too prominent" and cannot be avoided: "*It's a little bit too strong. I mean its presence is too prominent, so it makes you nervous. And it's also very big so it's not very fitting in this space*" (P9). 2) The bubbles were placed in a position higher than the floor, which may induce a misperception about participants being able to collide with the bubbles: "*I didn't really want to like or I wanted to move away from it and the bubbles I didn't want to cross them. Also they seemed like very heavy bodies in the space*" (P12). Additionally, 3) the bubble visualization was prioritized above the material elements of the environment, which is beneficial in grabbing user attention, but makes it difficult to perceive the relative distance between the participants and the bubbles (P8, P18): "*I'm getting a little bit confused about what is being visualized or I mean what the position is because I thought the sphere was supposed to be here somewhere but when I get closer, it's going farther away*." (P18)

4.3.6 User Expectations for Additional Traces

At the end of the study session, participants shared their thoughts about what types of traces (except for the ones used in the experiment) they expected, and how those traces might be used in the context of space evaluation. The aim of these questions is eliciting insights regarding which types of traces should be incorporated into the research tool in the future.

Emotion Traces

14 participants (P2, P3, P5, P6, P7, P8, P10, P12, P14, P16, P17, P18, P19, P20) expected to be able to experience traces that represent emotions or user experience from previous users. Several considerations regarding how to visualize such "emotion traces" were proposed:

- A number of participants wanted to have simple representations of emotion as common indications to inspire exploration, such as emojis, ratings of specific places, or colors that imply the users' emotional state: "*I think it would be nice to see this in a more...with multiplayer, with the other people leave the, like emojis and I can see what people like and what people don't like. Having that would be a nice condition*." (P18)

- Except for simple representations of emotion, participants expected to experience traces that disclose personal stories, such as events, moods, attitudes toward specific places, and so forth. For instance, making the bubble interactive and showing stories left by previous users when approaching.

Presenting emotions that are more detailed and personal was considered beneficial for evaluating specific locations and the space at large because detailed user stories and opinions may encourage more sharing of opinions. Meanwhile, seeking and revealing such traces will add a layer of playfulness to the evaluation process, and thus, inspire exploration as noted by P17 and P19: "Because all the visualizations you mentioned... it's more likely to guide the user to approach certain spots, but after approaching that spot they want to know more things than they need." (P17); "*Comments make it more personal. I think if it's a personal suggestion recommendation rather than the big data recommendation I would be more interested.*" (P19)

- Specifically, P5 mentioned the importance of keeping the user-generated traces separated from the original space: "*I hope it (user-generated traces) separated from the original scene, because, like the rating forms I just finished, the virtual world and the real world are two separate things...I feel the traces generated in two spaces can be divided. So I would like to know how the previous user was thinking about the space and how the future users look at it*." (P5)

- From a perspective of evaluating space design, some participants (P2, P8) believed that mapping emotional traces can also serve analytic purposes in the field of public space design: "*So maybe different people can also leave their emotion towards the space and then maybe the visualization of this can be a different type of heat map may be like emotion map, so maybe the color is warmer than that represents more people feel happy here and the color is colder than maybe represent people are more are sadder. Or maybe just non-emotional here*." (P8)

Sound Traces

6 participants (P7, P8, P9, P10, P13, P16) mentioned that sounds would be a great addition for enhancing the immersion in the virtual space. Interestingly, however, this expectation was driven by three motivations:

- Most participants (P8, P9, P10, P13, P16) preferred to have constant sounds accompanying the full-body motion traces, bringing richer immersion.

- Adding sound traces was considered a way of interacting with full-body motion traces and bubble visualization (P7, P10). Having a choice about whether to activate the sound in specific places was emphasized: "*With the bubble, I think like when I walked towards the red vibrating one and it's just boring. Yeah, sound definitely...or at least I can have the choice to listen or not because I wouldn't want to, like, very noisy all the time*." (P7)

- Without other types of traces, sound itself can be implemented solely to facilitate users to understand the atmosphere of the space in a unique way (P8). For instance, users perceive the intensity of the sound in different places without seeing any full-body motion traces. In this way, sounds may stimulate more imagination and inspiration for urban designers: "*I can even imagine if only this sound, the sounds are played without those moving figures is even more powerful because then it will trigger my own imagination. Yeah. So I think that would be very interesting*." (P8)

3.3 Conclusion

To summarize, we selected a virtual shopping street as the environment for situating trace visualizations: Line, Heatmap, Full-body Motion, Bubble. These visualizations were developed using resources obtained from the Unity Store. Subsequently, we conducted pilot tests featuring two tasks: 1) articipants were asked to rate each trace visualization and 2) utilize them to pinpoint locations of interest based on their personal preferences. Findings from the pilot tests led to refinements, including adjustments to the positions of trace visualizations, integrating evaluation questionnaires into the VR environment, and reframing the second task as "evaluating the environment by assigning emojis." The next chapter will delve into the details of the user study process and the resulting findings.

Chapter 5: Discussion

Intro

This chapter deliberates on the broader implications of designing and implementing trace visualizations in the context of evaluating outdoor public spaces. It also addresses the limitations of the work and translates them into considerations for improving the design of the research tool.

Overview

5.1 Discussion

The project was initiated with the idea that visualizing traces of previous users can facilitate understanding and exploration in VR environments by providing extra layers of information to the current users, which is applicable in the urban design domain to foster better evaluation of outdoor public space design. However, the visualization of traces can take various forms, representing specific information aspects of previous users' actions, which can elicit varying explorative behaviors. Consequently, the research question was formulated as follows: "How does observing trace visualizations affect users' explorative behaviors in VR environments?"

To address this question, we developed a research tool incorporating four types of trace visualizations in a VR shopping street: Line, Heatmap, Full-body Motion, and Bubbles. An experiment involving 20 participants was conducted to assess the influence of these trace visualizations on user exploration of the space.

The results suggested that different types of trace visualizations guide users' attention in distinct ways, fostering specific exploration patterns, including 1) Observing while moving; 2) Stopping to look around; 3) Direct movement; 4) Orderly exploration; and 5) Avoid approaching. For example, the heatmap encouraged more instances of "stopping to look around" as participants wanted to compare heatmap intensities in multiple areas, while full-body motion prompted more direct movements, with participants being drawn to the actions of 3D characters and moving towards them straightforwardly. Therefore, selectively implementing different types of traces can better support the evaluation of outdoor public space design. The study outcomes also offer practical implications for the implementation of trace visualizations.

5.1.1 Line

The line visualization appears to encourage a natural “following” behavior, supporting users to uncover most visited spots and places that are hard to be detected.

Encourage exploration through tailored routes

As discussed in Section 4.3.1, the existence of lines naturally encourages users to follow them, leading users to be drawn more towards the surroundings throughout the entire process of following a line, rather than concentrating solely on the starting and endpoints of the lines. Designers can leverage this characteristic to guide users along specific tailored routes, rather than emphasizing specific points of interest.

Users’ mindsets may induce different explorative behaviors

Participants’ enthusiasm for exploration varied based on the visibility of starting and end points of lines: Some participants found it less inspiring when these points were not visible, while others explored the space unaffected. It is reasonable to assume that participants who were affected paid more attention to identify the actions of previous users (“How others moved in the space”). In contrast, participants unaffected by the visibility of starting and end points treated the line visualization as guidance, supporting their own exploration ("How I would move in the space"). In real practice of evaluating public space design, designers should emphasize experiencing the environment over analyzing previous users' actions before the evaluation session.

Enhance the findability of places which are hard to be detected

The line visualization can be used to implicitly attract user attention to undetected places. Although users might be naturally drawn to locations where numerous lines start or end at, the abundance of options in these areas might deter them from following any single line. In contrast, single lines traversing through less detected areas evoke curiosity and are visually more indicative, providing a clearer guide for participants' exploration. When presenting the design outcomes of outdoor public spaces, this arrangement can be applied to facilitate users to discover places that are visually blocked by facilities.

The line visualization is not suitable for small open areas

As suggested in Section 4.3.1, in the scenario of exploring the space, the display of lines will likely not trigger curiosity if users can directly identify the end points from their standing positions because in such situation, users are already capable of observing the objects, buildings, and other elements surrounding the line without the need for movement. The finding suggests that the effectiveness of the line visualization is contingent on leading users to elements that are not immediately discernible. Hence, for the goal of driving more exploration, the line visualization, or or similar representations of user pathways, may not be well-suited for small open areas where users can comprehensively survey the entire space without movement.

Minimize disruption induced by teleportation

As confirmed in the user study, teleportation disrupts the continuity of the users' perception of the line. When following a line with teleportation, users may misinterpret that single line as multiple different parallels. Designers can present multiple pathways by using distinct colors, and instead of applying gradient effects, using shapes (e.g. footprint, arrow, etc.) to indicate directions might reduce misperceptions.

Match the trails of lines with available user pathways

Since many users would follow lines, failing to teleport to locations where trails of lines pass will bring frustration regarding users are restricted to perform like previous users. Designers should assign areas available for teleportation based on the positioning of line trails.

5.1.2 Heatmap

The line visualization appears to encourage a natural "following" behavior, supporting users to uncover most visited spots and places that are hard to be detected.

Heatmap is suitable for small areas

In the experiment, a significant number of participants frequently paused their movement to survey the heatmap intensity across various areas. It is reasonably assumed that the inability to grasp the entire heatmap at once prompted participants to take more actions to compare the heatmap intensity. In light of this, the heatmap proves more suitable for application in smaller areas, where users can readily inspect a substantial portion of the space with ease.

The potential improvement could be prioritizing the heatmap's layer in the system hierarchy. Assigning the heatmap to a higher layer ensures users can view the heatmap without obstructing other objects. However, this approach may elevate distraction levels and disrupt the overall observation of the environment. Therefore, this improvement might require a reduction in heatmap transparency, with thorough evaluation in future studies to assess its effectiveness.

Adjust visual elements to be consistent with the environment

Users tend to shift their focus towards the heatmap rather than the surrounding environment when the heatmap becomes visually more prominent than the material textures in the environment. To encourage exploration, designers should consider adjusting the heatmap's color and transparency to be less conspicuous than the material textures in the environment, which will mitigate distraction and allow more observation of the environment.

Make the heatmap more granular

Moreover, considering user feedback indicating that the heatmap becomes less informative when evenly distributed, we posit that enhancing the granularity of the heatmap to align with the actions of individual users, rather than representing aggregated gathering situations, might foster user exploration.

5.1.3 Full-body Motion

As its close resemblance to the real world scenarios, the full-body motion visualization

Emphasize the usage scenarios of the space
As demonstrated in the findings (Chapter 4), users may focus more on 3D characters' actions and the objects they interact with. One example is users paying attention to posters' contents if there is a 3D character who is depicted as reading a poster. To underscore the evaluation of public spaces, designers may apply full-body motion visualization in a way that emphasizes functions of specific spatial properties and the potential user interactions afforded by them. For instance, assigning full-body motion visualization to facilities and highlight intended use situations, thereby enhancing users' spatial awareness.

Emphasize the ambiance of the space
Conversely, the presence of full-body motion visualization naturally express the ambiance of the environment. In open areas lacking significant facilities, Designers might use less active animations for 3D characters to convey ambiance while preventing users from being overly distracted by the characters' actions.

Match transparency to the environment's lighting conditions
The presence of 3D characters with transparency appear to be lighter in sunny areas while becoming more visible in shadowy areas. Designers should adjust transparencies of visual elements according to the environmental lighting conditions or use alternative visual elements. As some participants suggested, designers may also intentionally utilize this feature to emphasize objects in shadowy areas.

5.1.4 Bubble

The line visualization appears to encourage a natural "following" behavior, supporting users to uncover most visited spots and places that are hard to be detected.

Less intrusive visual enhancer
As detailed in Chapter 4, certain participants noted that the inclusion of the bubble visualization enhanced the impact of the full-body motion visualization by implying the emotional states (e.g., excitement) of the 3D characters. Given that creating intricate animated 3D characters is time-consuming, urban designers can employ visual enhancers in a similar fashion of the bubble visualization, on 3D characters or specific facilities and locations, to illustrate intended atmosphere (e.g. quiet, exciting, etc.). Conversely, bubbles could also be used by citizen users to signify the atmosphere or vitality level they aspire to experience in different locations.

Minimize the distractions
Bubbles cause distractions because it occupies a large proportion of users' visual areas and appear in a position higher than the floor, which induce a misperception about users being able to collide with the bubbles. Designers may further reduce the flowing effect frequency and blur the boundaries of the bubbles to counter the distracting effect. Further more, while bubbles are able to attract user attention directly due to its' placement in a visual layer higher than other objects, it is difficult to perceive their distances. The visualization should be put in a visual layer lower than the material elements of the environment.

5.1.5 Implementing Trace Visualizations in VR

This section contains general considerations for implementing trace visualizations in VR. They are applicable regardless what type of trace visualizations are embedded.

Concerning VR setting

Before implementing a trace visualization, designers should consider its transferability in regard to VR settings. Different features for movement, rotation, ways of selecting objects may influence the perceptions of the implemented trace visualizations.

Extension based on simple elements

Trace visualizations serve to represent specific aspects of information related to prior space usage. In public spaces, a multitude of user behaviors can be driven by various factors. Integrating multiple design elements (e.g., size, shape, motion, color) into one trace visualization may introduce uncertainty, as different elements could evoke diverse associations. Take the bubble visualization, for instance; size (big/small), color (red/white), and flowing effect (high frequency/low frequency) were employed to convey an atmosphere (exciting/quiet), but some participants associated these elements with different meanings respectively. Designers should consider to focus on one or two major elements instead of combining multiple design elements, especially when designing traces that represent abstract information (e.g. emotion, space vatality, etc.).

Emphasizing Specific Aspects of the Space

In Chapter 4, it was observed that the presence of full-body motion traces led participants to concentrate more on the visualization and the virtual objects interacted with by the characters (e.g., advertisement board). The use of full-body motion traces emphasized the local social atmosphere. Conversely, during the examination of heatmap and bubble visualizations, participants tended to focus more on the overall environment. For example, they might identify an open-air restaurant without paying specific attention to the details on the tables. The line visualization proved effective in inspiring exploration, especially when participants were less familiar with the space. However, as familiarity increased, the line visualization's efficacy diminished. Therefore, designers should carefully select and emphasize specific types of visualizations based on the intended design purposes.

5.2 Limitations

This section discusses limitations in prototyping and experiment design, and further, proposes potential improvements to certain points.

5.2.1 Limitations in Prototyping

VR Environment Setting

The virtual shopping street used in this study is not a closed space, which means participants can directly see the background materials (a series of mountains, in this case). In a few cases, participants' exploration were affected by the background instead of only focusing on the public space set in the center. To ameliorate, we can employ models of an entire city block and limit the experiment in a small area.

5.2.2 Study Limitations

Selection of Traces

The research only includes trace visualizations that are commonly used for representing user behaviors in both public space design domain including user pathway, gathering situation, detailed user behaviors, and space vitality. Due to the time constraint, other types of traces, such as haptics, sounds, emotions, were not integrated. Incorporating additional types of trace visualizations. Future work should consider integrating emotion traces (see section 4.3.6) into the research tool since it discloses the additional layer of information regarding previous users' experience and with the potential of promoting triangulation of multiple types of trace visualizations.

Think Aloud During the Exploration

Participants were requested to describe their experiences regarding the perceptions of trace visualizations and its influences on their exploration during the entire process of “Observation” and “Evaluation” tasks. Although employing the think aloud method helps generating more responses, participants' exploration processes were disrupted in some cases. For instance, participants may stop exploration when describing their experiences.

Starting Position

Since all the observation tasks were arranged in an uninterrupted session, every participant took a different starting position for observing every trace visualization. Although most participants explored the space with each trace visualization quite extensively, the difference in starting points may affect the exploration patterns performed subsequently.

Selection of The Public Space

Individuals' familiarity of a public space alters their perception of the space (Jaalama et al., 2021). The virtual shopping street selected in this study is not the simulation of a real world space. As a result, participants perceived the shopping street by imagining themselves as potential users. For better investigating the effects of trace visualization in the urban design context, the ideal setting could be incorporating an actual model of public space redesign and recruiting real citizen users.

5.3 Conclusion

The project studies the influences of the four types of trace visualizations on user exploration behaviors in a VR outdoor public space. The results reveal that each type of trace visualization fosters distinct exploration patterns. This differentiation can prove advantageous when applied for specific purposes in the evaluation of public spaces, such as guiding users to unnoticed areas or directing attention to detailed space usage behaviors. These findings offer valuable insights for the implementation of trace visualizations within the context of public space evaluation, particularly in VR settings. Future research can focus on incorporating trace visualizations of abstract human information, such as emotions, and explore the triangulation of multiple types of trace visualizations. In conclusion, the design of the research tool facilitates the exploration of trace visualizations. It can serve as a prototype system for assessing other types of trace visualizations and holds potential for further development as a practical tool for the evaluation of public space design.

5.4 Personal Reflection

This graduation project is my first attemp of conducting research project in the field of VR. Initially, I started the project with an interest in VR and asynchronous interactions, inspired by many design projects that fuel such interactions in public display. This research area was very fresh and intriguing to me and I still remember a lot of potential topics emerged during my search of literatures, such as visualizing memories, traces and visual perspectives, and so forth. However, as an IDE graduation project, the importance of incorporating design components was stressed throughout the project process. Consequently, my direction was reoriented towards leveraging trace visualizations to support the evaluation of public space design.

Introspecting the project process, the top challenge was navigating the transition between designer and researcher mindsets. While design projects often necessitate a flexible approach, research projects require a more structured methodology. I was a bit lost at some points, struggling to meet the requirements of both aspects. But eventually, I was able to overcome the dilemma and embraced numerous fresh experiences, from building the VR system to designing the user study.

This is a really fun project in a way that brings a blend of challenges and illuminating moments. I am very happy to have this opportunity to dive into the realm of VR-related research, encountering unique joys distinct from those I acquired by practicing design. As the journey nears its end, I intend to refine my workflow and eagerly look forward to explore other topics of research in the VR domain.

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Appendix - Pre-study interview Protocol

1. Introducing the overall project goals to the participants

(Script)
"Thank you for participating in this session. My project is about designing and understanding social traces in VR for supporting a better urban co-design decision-making."

"Conventionally, urban design often comes from big-scale data, but now, many studios and municipalities are trying to engage with general citizen into the urban design because they are the ones who actually use the space. A recent example is Olifantenpad CS, a VR application that allows citizen to design the space directly and then they will discuss the plan with the design team and vote for the most suitable plan."

"So firstly, I would like to ask you about your workflow when you (re)design a public space."

2. Filling-in form

General information

- Personal information:
  - Name / Gender / Age / Nationality / Profession
- Experience:
  - Whether the participant has conducted field research and user feedback collection before when designing public spaces.
  - (how many years, what experience, what domains)

3. Understanding the current urban design practice (Interview)

General flow/pattern for design & decision-making

- Think about a urban design project, guide me through the process
- At the very beginning of a project, how would you learn the space you will design for?
  - What is that project about
  - Data / Discussion with clients / Field observation / Others?
  - What information you want to know before ideation?
    - Why those information are important?
    - Can you share a recent example?
  - Challenges

- Did you often conduct field observation when proceeding with public space design?
  - What would you pay attention to?
    - Would you interview users/citizen/residents in this process?
      - What questions would you ask?

- In general work flow, is there any information or aspects about the space often not being explored?
  - (If yes) Why?
    - How this would affect you when doing design?

- When designing a public space, to what extent you feel understand how users/citizen use the space in their daily life?
  - (If understand) How would you investigate users daily usage and experience?
  - (If not)

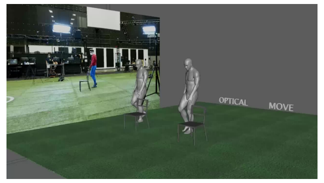
↓

- Do you think understanding user behaviors/interactions would be beneficial for making design decisions?
  - Why? / Why not?
  - What aspects do you like to know?

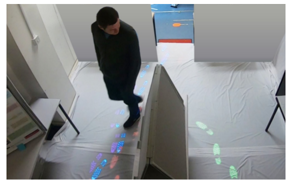
- Would you collect user feedback throughout the processes?
  - When you do this? How often?
  - (If yes) How would you do it? Which methods do you use?
  - (If not) How would you evaluate your design?
- In Ideal situation, how would you do it? What would you like to know?

3. Showing examples of trace visualization and use situations

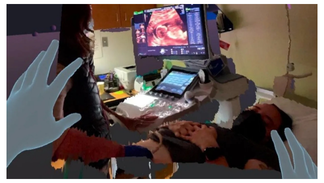
“Thank you for telling me about the working process. Considering we want to understand how users actually interact with and within the space. Actually there are already certain technologies that enable capturing traces of use and represent them in virtual environment. Here is some examples of trace visualizations…(showing photos)”



Move.ai

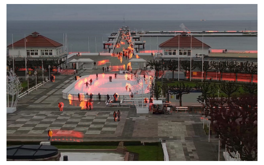


(Albarrak et al., 2021)



Wist

(Stellmacher et al., 2021)



(Roberto., 2020)

Strategies of picking traces

- How could this trace visualization helps your work? In what way?
- If you can visualize use traces, what use situations to apply can be beneficial
  - Why?
  - How focusing on those situations would affect your design decisions?
- How you would like to visualize traces for those use situations?
  - (Provide photos and tools for the interviewees to draw the trace visualizations)
  - Why you like to visualize these traces? What information or aspects you would like to emphasize?

Goal of the visualizations

- In what ways you think visualizing social traces can help you making design decisions?
  - Emphasizing negative/positive user interactions?
  - Understanding which areas are used more/less often?
  - Understanding people’s route selection?
  - Others…?
- Do you think visualizing social traces will allow a more clear communication with clients?
- Would you like to incorporate this “exploring social trace” session into your current workflow?
  - Why or why not?

Appendix - User Study Interview Question List

[Script]
“Thank you for participating in this experiment. I would like to ask you some questions about your experience in the virtual environment.”

- When you enter a space in general without specific purposes, how would you normally determine what you want to see in that space? What strategies do you employ?
- How do you interpret the meaning of each visualization?
  - How did you feel when you moved in the space with the presence of traces (line, heatmap, motion, sound)?

- Do you think being able to see these traces left by previous users is helpful for you to understand the space?
  - Why or why not?
  - (Specify specific visualizations)

- Do you feel inspired to explore the space when you can see those trace visualizations?
  - Why or why not?
  - (Specify specific visualizations)

- Did the trace visualizations affect where you want to explore and how you would move in the virtual space?
  - How?

- Is there any trace visualizations confused you in your exploration?
  - Why or why not?
  - (Specify specific visualization)

- (If modified the visualizations) What was your consideration when modifying the visualizations? Why did you combine them in that specific way?

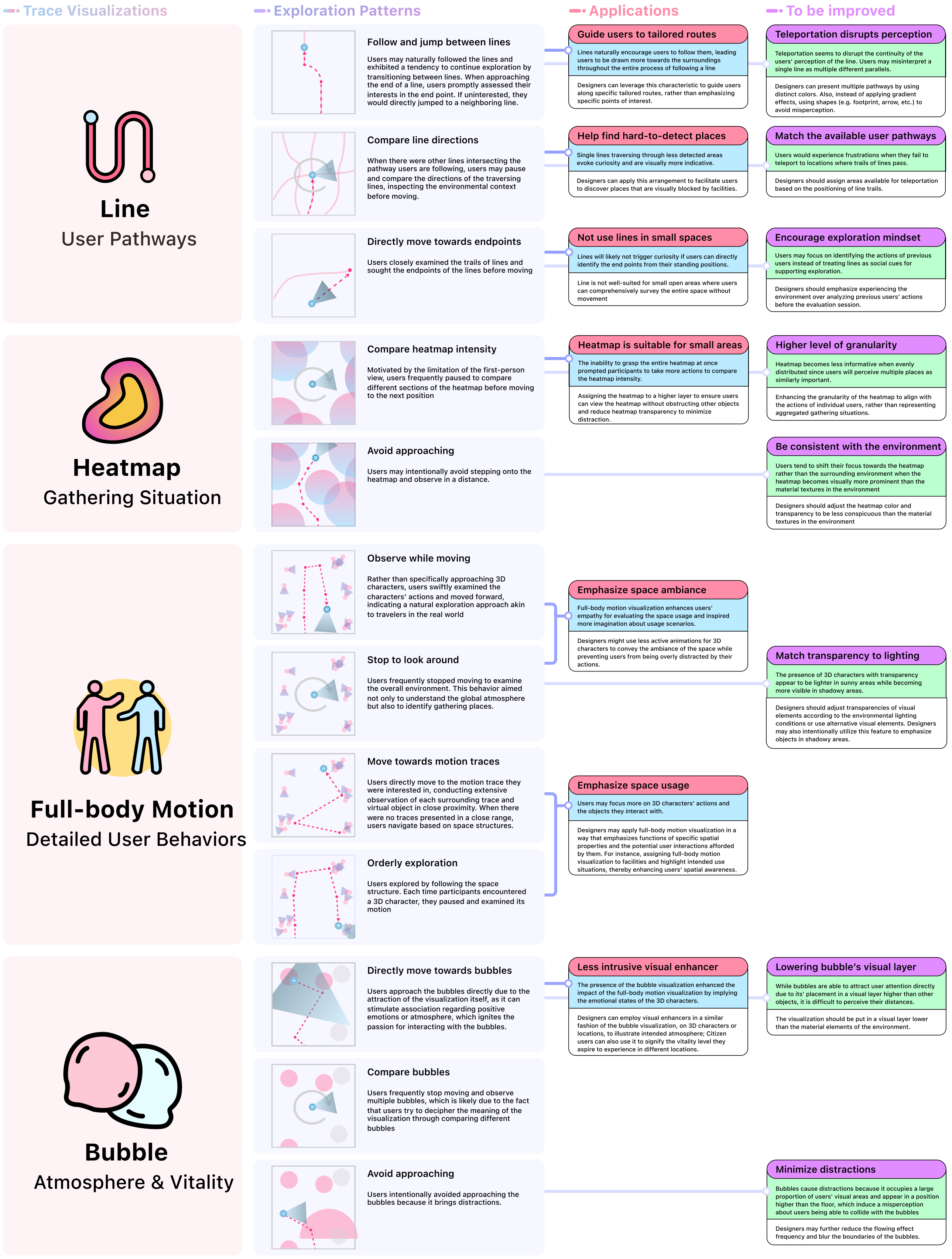
- How did you navigate in the Evaluation task? Did the trace visualizations affect you?

- Did the trace visualizations affect where you assign emojis and what emojis you selected?

- Is there any other types of traces you want to see when evaluating a space?

- Is there any other types of traces you want to leave for future users?

Appendix - Summary of the main take-aways



Trace Visualizations · Exploration Patterns · Applications · To be improved

Line
User Pathways

Follow and jump between lines
Users may naturally followed the lines and exhibited a tendency to continue exploration by transitioning between lines. When approaching the end of a line, users promptly assessed their interests in the end point. If uninterested, they would directly jumped to a neighboring line.

Guide users to tailored routes
Lines naturally encourage users to follow them, leading users to be drawn more towards the surroundings throughout the entire process of following a line
Designers can leverage this characteristic to guide users along specific tailored routes, rather than emphasizing specific points of interest.

Teleportation disrupts perception
Teleportation seems to disrupt the continuity of the users' perception of the line. Users may misinterpret a single line as multiple different parallels.
Designers can present multiple pathways by using distinct colors. Also, instead of applying gradient effects, using shapes (e.g. footprint, arrow, etc.) to avoid misperception.

Compare line directions
When there were other lines intersecting the pathway users are following, users may pause and compare the directions of the traversing lines, inspecting the environmental context before moving.

Help find hard-to-detect places
Single lines traversing through less detected areas evoke curiosity and are visually more indicative.
Designers can apply this arrangement to facilitate users to discover places that are visually blocked by facilities.

Match the available user pathways
Users would experience frustrations when they fail to teleport to locations where trails of lines pass.
Designers should assign areas available for teleportation based on the positioning of line trails.

Directly move towards endpoints
Users closely examined the trails of lines and sought the endpoints of the lines before moving

Not use lines in small spaces
Lines will likely not trigger curiosity if users can directly identify the end points from their standing positions.
Line is not well-suited for small open areas where users can comprehensively survey the entire space without movement

Encourage exploration mindset
Users may focus on identifying the actions of previous users instead of treating lines as social cues for supporting exploration.
Designers should emphasize experiencing the environment over analyzing previous users' actions before the evaluation session.

Heatmap
Gathering Situation

Compare heatmap intensity
Motivated by the limitation of the first-person view, users frequently paused to compare different sections of the heatmap before moving to the next position

Heatmap is suitable for small areas
The inability to grasp the entire heatmap at once prompted participants to take more actions to compare the heatmap intensity.
Assigning the heatmap to a higher layer to ensure users can view the heatmap without obstructing other objects and reduce heatmap transparency to minimize distraction.

Higher level of granularity
Heatmap becomes less informative when evenly distributed since users will perceive multiple places as similarly important.
Enhancing the granularity of the heatmap to align with the actions of individual users, rather than representing aggregated gathering situations.

Avoid approaching
Users may intentionally avoid stepping onto the heatmap and observe in a distance.

Be consistent with the environment
Users tend to shift their focus towards the heatmap rather than the surrounding environment when the heatmap becomes visually more prominent than the material textures in the environment
Designers should adjust the heatmap color and transparency to be less conspicuous than the material textures in the environment

Full-body Motion
Detailed User Behaviors

Observe while moving
Rather than specifically approaching 3D characters, users swiftly examined the characters' actions and moved forward, indicating a natural exploration approach akin to travelers in the real world

Stop to look around
Users frequently stopped moving to examine the overall environment. This behavior aimed not only to understand the global atmosphere but also to identify gathering places.

Emphasize space ambiance
Full-body motion visualization enhances users' empathy for evaluating the space usage and inspired more imagination about usage scenarios.
Designers might use less active animations for 3D characters to convey the ambiance of the space while preventing users from being overly distracted by their actions.

Match transparency to lighting
The presence of 3D characters with transparency appear to be lighter in sunny areas while becoming more visible in shadowy areas.
Designers should adjust transparencies of visual elements according to the environmental lighting conditions or use alternative visual elements. Designers may also intentionally utilize this feature to emphasize objects in shadowy areas.

Move towards motion traces
Users directly move to the motion trace they were interested in, conducting extensive observation of each surrounding trace and virtual object in close proximity. When there were no traces presented in a close range, users navigate based on space structures.

Orderly exploration
Users explored by following the space structure. Each time participants encountered a 3D character, they paused and examined its motion

Emphasize space usage
Users may focus more on 3D characters' actions and the objects they interact with.
Designers may apply full-body motion visualization in a way that emphasizes functions of specific spatial properties and the potential user interactions afforded by them. For instance, assigning full-body motion visualization to facilities and highlight intended use situations, thereby enhancing users' spatial awareness.

Bubble
Atmosphere & Vitality

Directly move towards bubbles
Users approach the bubbles directly due to the attraction of the visualization itself, as it can stimulate association regarding positive emotions or atmosphere, which ignites the passion for interacting with the bubbles.

Less intrusive visual enhancer
The presence of the bubble visualization enhanced the impact of the full-body motion visualization by implying the emotional states of the 3D characters.
Designers can employ visual enhancers in a similar fashion of the bubble visualization, on 3D characters or locations, to illustrate intended atmosphere; Citizen users can also use it to signify the vitality level they aspire to experience in different locations.

Lowering bubble's visual layer
While bubbles are able to attract user attention directly due to its' placement in a visual layer higher than other objects, it is difficult to perceive their distances.
The visualization should be put in a visual layer lower than the material elements of the environment.

Compare bubbles
Users frequently stop moving and observe multiple bubbles, which is likely due to the fact that users try to decipher the meaning of the visualization through comparing different bubbles

Avoid approaching
Users intentionally avoided approaching the bubbles because it brings distractions.

Minimize distractions
Bubbles cause distractions because it occupies a large proportion of users' visual areas and appear in a position higher than the floor, which induce a misperception about users being able to collide with the bubbles
Designers may further reduce the flowing effect frequency and blur the boundaries of the bubbles.

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name Tan
initials Z.T. given name Zhuowen
student number 5581478
street & no.
zipcode & city
country
phone
email

Your master programme (only select the options that apply to you):
IDE master(s): ○ IPD ● DfI ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign
○ Tech. in Sustainable Design
○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Gijs Huisman dept. / section: HCD
** mentor Tomasz Jaśkiewicz dept. / section: HCD
2nd mentor Abdallah El Ali
organisation: Centrum Wiskunde & Informatica
city: Amsterdam country: The Netherlands
comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Gijs Huisman date 05 - 06 - 2023 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _______ EC

List of electives obtained before the third semester without approval of the BoE

○ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name _______ date - - signature _______

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ○ APPROVED ○ NOT APPROVED

Procedure: ○ APPROVED ○ NOT APPROVED

comments

name _______ date - - signature _______

Visualizing social traces for better urban design decision-making

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 05 - 06 - 2023

end date 10 - 11 - 2023

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Currently, in the workflow of designing public spaces, little attention is given to understanding user behaviors. Designing a public space typically starts in big-scale planning and only considers the experience of an individual's first-person perspective in the evaluation phase. To create democratic cities, researchers advocate participatory approaches in urban design processes and implement VR technology to effectively include residents and the general public in decision-making [1, 2, 3]. However, what had not gained full attention is the stage of understanding user behaviors before the ideation phase begins. Recent technology advancement that enables tracking social traces (traces that unfold prior human interactions with the space) exhibits great potential to support this trend by helping designers understand how a space is being used, such as capturing full-body motion without markers [4], converting video recording to 3D experiences [5], and visualizing walking trajectories [6]. Although these technologies have not been widely implemented in urban design practice, understanding users' physical activities is considered highly valuable in designing outdoor public spaces [7] and spatial-related interactive experiences [8]. However, considering the diversity of human activities, visualizing a social trace may explain or emphasize only a few aspect of prior human actions. For instance, a visualized footprint may indicate a person's movement without telling the motion of his/her upper body, while a realistic 3D representation of a moving person might be useful for conjecturing that person's emotion without highlighting which area he/she spends the longest time. Therefore, it is valuable to explore how visualizing social traces in VR may help urban designers' decision-making.

Considering VR has the potential to aid the entire workflow of urban design [9] through improving client participation, enabling co-editing city models, and enhancing the final design presentation, it is selected as the media for inspecting social traces in this project. This project aims at investigating what are considered social traces from urban designers' perspectives, and how different visualizations of social traces affect urban designers' decision-making behaviors. The expected outcome includes design implications derived from the research findings and a VR interface that enables users (designers or general citizens who participate in the design process) to observe multiple social trace visualizations.

[1] Fabian Dembski, Uwe Wössner, Mike Letzgus, Michael Ruddat, and Claudia Yamu. 2020. Urban Digital Twins for smart cities and citizens: The case study of herrenberg, Germany. Sustainability 12, 6 (2020), 2307.
[2] Jos P. van Leeuwen, Klaske Hermans, Antti Jylhä, Arnold Jan Quanjer, and Hanke Nijman. 2018. Effectiveness of virtual reality in participatory urban planning. Proceedings of the 4th Media Architecture Biennale Conference (2018).
[3] Home - OlifantenpadCS. Retrieved April 26, 2023 from https://olifantenpad.com/home/
[4] Move ai. Retrieved May 20, 2023 from http://www.move.ai/
[5] Wist | Step Inside Your Memories. Retrieved April 26, 2023 from https://wistlabs.com/
[6] Beatrice Monastero and David K. McGookin. 2018. Traces. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (2018).
[7] Vikas Mehta. 2009. Look closely and you will see, listen carefully and you will hear: Urban Design and social interaction on streets. Journal of Urban Design 14, 1 (2009), 29–64.
[8] Salla Eilola, Kaisa Jaalama, Petri Kangassalo, Pilvi Nummi, Aija Staffans, and Nora Fagerholm. 2023. 3D visualisations for communicative urban and landscape planning: What systematic mapping of academic literature can tell us of their potential? Landscape and Urban Planning 234 (2023), 104716.
[9] Virtual reality in planning. Retrieved May 22, 2023 from https://planning.calpoly.edu/virtual-reality-planning

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image / figure 1: A VR application that enables designers and residents design the public space

image / figure 2: Some examples of social trace visualization

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PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The project is situated in the context of urban design and aims at understanding how visualizations of social traces may support urban designers' decision-making behaviors. The following research questions will be addressed:

RQ 1: What are urban designers' perceptions about social traces (what are included, how they hope social traces to be visualized, etc.)?
RQ 2: Does viewing different social trace visualizations elicit different design considerations (regarding how to arrange the space, provide facilities, facilitate or discourage the existing user behaviors)?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The project focuses on understanding how the visualizations of social traces in virtual environments affect urban designers' decision-making when designing a public space; and designing a VR interface that enables transitions between multiple visualizations to support research and design activities.

Within the scope of exploring social trace visualizations in VR, the possible outcomes may include:

1. Using the user study (through survey, workshop, etc) results as basis to generate social trace visualizations that represent (certain aspects of) prior user interactions with the space.

2. Through conducting experiments, the results might be used to generate implication for designing social trace visualizations and improving the workflow of urban design practice.

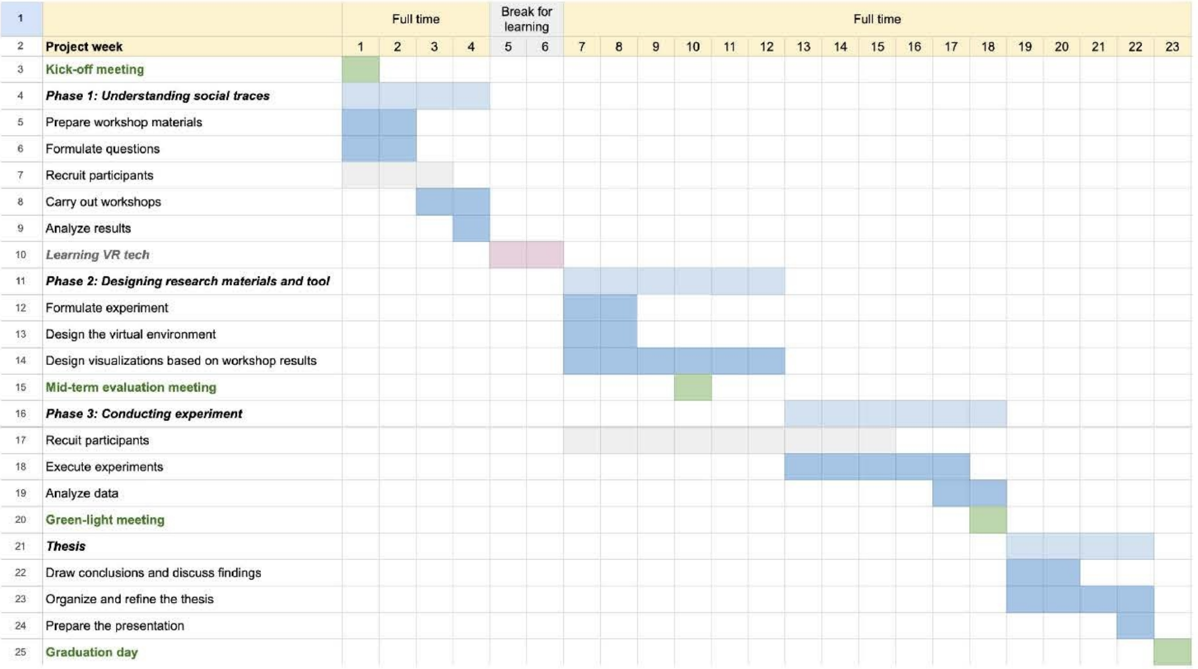
3. The insights gathered from workshops and experiments may support designing a VR interface that enables users to view multiple social trace visualizations.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 5 - 6 - 2023

10 - 11 - 2023 end date



1		Full time				Break for learning		Full time																
2	**Project week**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	**Kick-off meeting**	■																						
4	***Phase 1: Understanding social traces***	■	■	■	■																			
5	Prepare workshop materials	■	■																					
6	Formulate questions	■	■																					
7	Recruit participants	■	■	■																				
8	Carry out workshops			■	■																			
9	Analyze results				■																			
10	***Learning VR tech***					■	■																	
11	***Phase 2: Designing research materials and tool***							■	■	■	■	■	■											
12	Formulate experiment							■	■															
13	Design the virtual environment							■	■															
14	Design visualizations based on workshop results							■	■	■	■	■	■											
15	**Mid-term evaluation meeting**										■													
16	***Phase 3: Conducting experiment***													■	■	■	■	■	■					
17	Recuit participants							■	■	■	■	■	■	■	■	■								
18	Execute experiments													■	■	■	■	■						
19	Analyze data																	■	■					
20	**Green-light meeting**																		■					
21	***Thesis***																			■	■	■	■	
22	Draw conclusions and discuss findings																			■	■			
23	Organize and refine the thesis																			■	■	■	■	
24	Prepare the presentation																						■	
25	**Graduation day**																							■

The project will be separated into three phases:

1. Understanding social traces;
The first phase will focus on conducting workshops to understand how urban designers perceive social traces (what will be considered as social traces) and the ways to visualize them.

2. Designing research materials and tools;
The objectives of this phase include creating social traces based on the workshop outcomes, and building a virtual environment where the social traces and an interface that enables the display of them can be situated.

3. Conducting the experiment.
The last phase is carrying out the experiment including finalizing experiment task flow, collecting and analyzing data, interpreting research results, and formulating research paper.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

As an UX designer, I've been used to investigating user needs with qualitative methods and completing design with constraints of time, budget and information. I'm excited to carry out this research-focused graduation project during which I have an opportunity to proceed the study with controlled conditions and a more objective data collection. In this project, I aim to translate research findings to formulate design implications and tools for supporting urban design workflow.

I have obtained UX design knowledge and techniques from previous education and industrial projects. Both courses, Context & Conceptualization and DFI Research Methodology fueled me with fundamental research skills in both design and research contexts.

What I intend to strengthen are:
1. Techniques to create research materials/probes.
Although I've implemented research probes in some real scenarios, in most cases, interview and thematic analysis are the primary means to investigate a problem due to time limitation. As described in the "Assignment", the first phase of my project will be conducting workshops, and thus, providing a space for practicing probe design.

2. Quantitative approach.
As I stated above, I use qualitative methods extensively in my design projects. I'm seeking opportunities to enhance my knowledge in applying quantitative methods to support research and design outcomes.

3. Techniques to design in/for VR
As my previous design practices highly focused on app, websites and interactive objects, designing VR-related experiences and interfaces discloses a new space for me to apply my skills.

4. Formalizing a research.
Since I intend to seek PhD opportunities after my graduation, I will be able to familiarize myself with the full aspects of running a research project along with the capabilities required, such as managing time, coordinating with collaborators/mentors and adapting design skills into the research.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.