MASTER

# Measuring User-experience in High-Rise Urban Areas Using Immersive Virtual Reality and Eye-Tracking Observations

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*Award date:*
2024

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30-05-2024

# Master Thesis

MEASURING USER-EXPERIENCE IN HIGH-RISE URBAN AREAS USING IMMERSIVE VIRTUAL REALITY AND EYE-TRACKING OBSERVATIONS

Eindhoven University of Technology

Department of the Built Environment
Architecture, Building and Planning / Urban Systems and Real Estate
Construction Management and Engineering

# Measuring User-experience in High-Rise Urban Areas Using Immersive Virtual Reality and Eye-Tracking Observations

By

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MSC THESIS

2023 - 2024

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|---|---|
| Programs: | Architecture, Building & Planning<br>Construction Management & Engineering |
| Date of defence: | May 30th, 2024 |
| Student ID: | 0997918 |
| Study load (ECTS): | 60 |
| Track: | Urban Systems and Real Estate |
| Courses | 7Z45M0 – 7CC40 |

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## Preface

In February 2022, my thesis journey started. Human behaviour has been a topic that has triggered my curiosity for a long time, so when I was orienting on a graduation topic, this was the direction I was looking for in. Using immersive virtual reality to investigate how attributes of the built environment influence user-experience sounded like a great topic to finish my double degree with. Throughout my graduation project I have been able to learn new programs, such as Unity and MATLAB, an acquire new skills, such as coding in C# and setting up experiments in VR. This graduation topic came with quite some challenges to overcome. In the end I was not able to execute the experiments as I had once intended, yet I am proud of what I was able to achieve.

At first I would like to thank my supervisors: Astrid Kemperman, Dujuan Yang and Gamze Dane, who guided me along by provided feedback on the steps taken and text provided, who I could brainstorm with on how to tackle an issue or how to continue, and most importantly who helped me along so I could bring this project to a successful conclusion. Next to that, I would like to thank Pauline van den Berg, for being my supervisor along Astrid at the beginning of the project. I would like to thank the people of EASI Digital Twin Lab, for letting me use their equipment, taking the time to explain the equipment and software to me, and to help me solve the problems I ran into regarding the VR experiment.

Additionally, I would like to thank all participants, without your time I would not have been able to gather the dataset I have. I am very grateful for all friends, family and colleagues who spared an hour of their time to join me in the Digital Twin Lab, those who could not help me by participating, but were there along the way, supporting me, listening to my thoughts and frustrations, helping me untangle my thoughts and clear my mind. Most importantly, who helped me remember to relax and have fun.

## Summary

Cities are growing, and forecasts predict that two thirds of the world's population will live in a city by 2050 (Bele & Wasade, 2016). This urbanisation leads to the development of high-rise environments, as densification is often preferred over expansion. Urbanisation and the development of high-rise environments pose risks to the well-being of the users of these areas (Resch et al., 2020; Spanjar & Suurenbroek, 2020). Specifically, high-rise environments have a negative effect on the restorativeness of its users, trigger stress responses and are associated with higher risks of geriatric depression (Ho et al., 2017; Spanjar & Suurenbroek, 2020). Therefore, it has become of increasing importance to design and develop healthy high-rise environments, which take the interaction with, and effect on its users into account (Fathi et al., 2020; Fu et al., 2021; Resch et al., 2020; Spanjar & Suurenbroek, 2020; Weijs-Perrée et al., 2020). User-centred research approaches on the built environment allow researchers to gain more insight into these relations. These insights can then be used to plan and design more attractive cities, which service citizens' needs and contribute to regeneration of urban spaces, avoiding deterioration. Moreover, they could identify deficiencies in the design that experts have overlooked. There is an increasing interest in evidence-based interventions in the built environment and more research is needed to create understanding on the interaction between human and environment, including both conscious and unconscious processes (Hollander et al., 2021; Llinares et al., 2020). In order to measure this interaction properly, the context in which the experiments take place needs to be controlled (Pykett et al., 2020). By creating representations of the built environment, e.g., using virtual reality (VR) technology, these variables can be controlled.

This research aims to address this research gap and to provide more insights for designing more attractive high-rise environments by studying the experience of users of high-rise areas, answering the main research question:

*What characteristics of high-rise areas influence the user-experience, when modelled in an immersive virtual environment and using eye-tracking observations?*

At first a literature review was conducted to define "user-experience" and gain insights in preceding research studies on the topic. From said literature review followed that there is no single definition for user-experience. In similar studies, four main emotions were used to describe user-experience: safety, comfort, annoyance, and happiness. Thus, user-experience was chosen to be defined as a positive or negative value, computed by merging the ratings on a 5-point Likert scale of the four main emotions. The stimulus-organism-response model provided a framework which explained how people perceive their environments. From this framework it could be derived that, whilst the environment exists out of a lot of separate elements, people perceive it as a whole. Their previous experiences and personal characteristics function as response moderators, which influence their internal response to the environment and/or representation of the environment. Ultimately this leads to a certain behavioural response, such as an approach or avoidance behaviour. Several characteristics of the built environment were found to influence the user-experience, but they were mostly mapped using qualitative research methods such as self-reporting and surveys. Personal characteristics that could function as response moderators included age, gender, urbanisation

level of living environment, frequency of visits to high-rise environments, personality, and mood.

A VR experiment was designed and executed in this study, during which participants would walk through a virtual environment and report on their user-experience. The environmental attributes incorporated in the experiment were height of buildings, variation in height, grass coverage, number of trees, clustering of trees and presence of water. Each attribute had two attribute levels. Orthogonal experimental design was used to create 8 different models, whilst avoiding correlation between the different combinations. The attributes were varied in the base model of the Eindhoven station area redevelopment by CoHeSIVE (2022b). Unity was used to create the virtual environment. A participant ID script, position logger, rotation logger and eye-collider interaction script were added to the model to log the behaviours. A total of 32 participants participated in the experiments, which incorporated a visit to three of the eight models, and answering multiple choice, open, and interview questions on their experiences and behaviour. The Unity model created logfiles for the position and eye-interaction analyses. The interview questions, along with the open questions were analysed using an open, descriptive coding method. One of the most important findings was that the presence of greenery did improve the user-experience to some extent. However, the amount of greenery should not be too much, as it becomes overwhelming and should not interfere with the walking path. The addition of fountains was generally seen as fun, but also for this attribute applied that the placement should not interfere with the walking path. In the models with skyscrapers, the participants tended to feel “pushed out” and preferred to spend their time in the more open areas in the model. The eye-data was visualised using spikes to indicate the rotation of the HMD and analysed using count tables of the number of times an interaction with a collider object occurred. There were especially a lot of interactions with trees and the façades in the model. The scan path between the two was also the most observed sequence.

To answer the main research question, a fixed effects panel regression model was run to take into account that the personal characteristics do not vary over the three user-experience measurements. Also, this model did not have any statistically significant variables, which could be due to sample size. In general, it can be concluded that immersive virtual reality with eye-tracking possibilities is a promising tool to analyse and quantify user-experience. The answers given to the open and interview questions did correspond to the position analysis to some extent.

Nonetheless, there are also some limitations to such experiments. The view in the HMD is limited compared to the view in the real world, therefore, the participants had to rotate their head more, compared to in the real world. Next to that, the movements made do not translate completely to the movements in VR, creating a sort of distortion and/or delay in the view. By optimizing the design and the file that is run, the delays might decrease. Increasing the sample size may lead to more significant results.

The eye-tracking data could add more in-depth insights in how the participants process their environment and experiences. Remarks on the VR experiment were that the participants liked to be fully immersed in the environment, that the experiments had an explorative character with freedom of movement. Overall, they found it a fun experience and some indicated that the equipment was straightforward in use.

## Samenvatting

Steden groeien en prognoses voorspellen dat twee derde van de wereldbevolking in een stad zal wonen tegen 2050 (Bele & Wasade, 2016). Deze verstedelijking leidt tot de ontwikkeling van hoogbouwgebieden, omdat verdichting vaak de voorkeur krijgt boven uitbreiding. Verstedelijking en de ontwikkeling van hoogbouwgebieden brengen risico's met zich mee voor het welzijn van de gebruikers (Resch et al., 2020; Spanjar & Suurenbroek, 2020). Specifiek hebben hoogbouwgebieden een negatief effect op het herstelvermogen van de gebruikers, veroorzaken ze stressreacties en worden ze geassocieerd met een hoger risico op geriatrische depressie (Ho et al., 2017; Spanjar & Suurenbroek, 2020). Daarom is het steeds belangrijker geworden om gezonde hoogbouwomgevingen te ontwerpen en te ontwikkelen, die rekening houden met de interactie met en het effect op de gebruikers (Fathi et al., 2020; Fu et al., 2021; Resch et al., 2020; Spanjar & Suurenbroek, 2020; Weijs-Perrée et al., 2020). Gebruikersgerichte studies in de gebouwde omgeving stellen onderzoekers in staat meer inzicht te krijgen in deze relaties. Deze inzichten kunnen vervolgens worden gebruikt om aantrekkelijkere steden te plannen en te ontwerpen die voldoen aan de behoeften van de gebruikers en bijdragen aan de regeneratie van stedelijke ruimtes. Er is een toenemende interesse in op bewijs gebaseerde interventies in de gebouwde omgeving en er is meer onderzoek nodig om inzicht te creëren over de interactie tussen mens en omgeving, inclusief zowel bewuste als onbewuste processen (Hollander et al., 2021; Llinares et al., 2020). Om deze interactie goed te meten, moet de context waarin de experimenten plaatsvinden worden gecontroleerd (Pykett et al., 2020). Dit is mogelijk door representaties van de gebouwde omgeving te creëren, bijvoorbeeld met behulp van virtual reality.

Dit onderzoek heeft tot doel deze onderzoekskloof te adresseren en meer inzicht te bieden voor het ontwerpen van aantrekkelijkere hoogbouwomgevingen door de ervaring van gebruikers van hoogbouwgebieden te bestuderen en de belangrijkste onderzoeksvraag te beantwoorden:

*Welke kenmerken van hoogbouwgebieden beïnvloeden de gebruikerservaring wanneer gemodelleerd in een virtuele omgeving en met behulp van eye-tracking observaties?*

Eerst werd een literatuuronderzoek uitgevoerd om "gebruikerservaring" te definiëren en inzichten te krijgen in voorafgaande studies over het onderwerp. Uit dit literatuuronderzoek bleek dat er geen eenduidige definitie is voor gebruikerservaring. In soortgelijke studies werden vier hoofdemoties gebruikt om de gebruikerservaring te beschrijven: veiligheid, comfort, irritatie en geluk. Het stimulus-organisme-responsmodel bood een kader waarin werd uitgelegd hoe mensen hun omgeving waarnemen. Uit dit kader kon worden afgeleid dat, hoewel de omgeving uit veel afzonderlijke elementen bestaat, mensen het als geheel waarnemen. Hun eerdere ervaringen en persoonlijke kenmerken fungeren als responsmoderatoren, die hun interne reactie op de omgeving en/of representatie van de omgeving beïnvloeden. En uiteindelijk leidt dit tot een bepaalde gedragsreactie, zoals benaderings- of vermijdingsgedrag.

Er werden verschillende kenmerken van de gebouwde omgeving gevonden die de gebruikerservaring beïnvloeden, maar ze werden voornamelijk in kaart gebracht met behulp van kwalitatieve onderzoeksmethoden. Persoonlijke kenmerken die kunnen fungeren als

responsmoderatoren waren onder meer leeftijd, geslacht, verstedelijkingniveau van de leefomgeving, frequentie van bezoeken aan hoogbouwgebieden, persoonlijkheid en humeur.

Een VR experiment was ontworpen waarin participanten door de virtuele omgeving liepen en vragen beantwoordden over hun ervaring. De omgevingskenmerken die in het experiment werden opgenomen, waren de hoogte van gebouwen, variatie in hoogte van gebouwen, grasdekking, aantal bomen, clustering van bomen en aanwezigheid van water. Elk kenmerk had twee attribuutniveaus. Orthogonaal experimenteel ontwerp werd gebruikt om 8 verschillende modellen te maken, waarbij correlatie tussen de verschillende combinaties werd vermeden. De kenmerken werden gevarieerd in het basismodel van de herontwikkeling van het Eindhovense stationsgebied van CoHeSIVE (2022b). Unity werd gebruikt om de virtuele omgeving te creëren. Een deelnemers-ID-script, positie-logger, rotatie-logger en eye-collider interactiescript werden aan het model toegevoegd om het gedrag vast te leggen.

In totaal namen 32 deelnemers deel aan de experimenten, waarbij ze een bezoek brachten aan drie van de acht modellen en meerkeuze-, open- en interviewvragen beantwoordden over hun ervaringen en gedrag. En het Unity-model creëerde logbestanden voor de positie- en zicht-interactie analyses. De interviewvragen, samen met de open vragen, werden geanalyseerd met behulp van een open coderingsmethode. Een van de belangrijkste bevindingen was dat de aanwezigheid van groen de gebruikerservaring tot op zekere hoogte verbeterde. Echter, te veel groen werd ervaren als te overweldigend en het moet het wandelpad niet verhinderen. De toevoeging van fonteinen werd over het algemeen gezien als leuk, maar ook voor dit kenmerk gold dat de plaatsing het wandelpad niet moet verhinderen. In de modellen met wolkenkrabbers voelden de deelnemers zich vaak "weggedrukt" en gaven ze er de voorkeur aan hun tijd door te brengen in de meer open gebieden in het model. De zicht gegevens werden gevisualiseerd met spikes om de rotatie van de HMD aan te geven en werden geanalyseerd met tel tabellen van het aantal keren dat een interactie met een collider-object plaatsvond. Er waren vooral veel interacties met bomen en de gevels in het model. De interactiesequentie tussen de twee was ook de meest waargenomen sequentie.

Om de hoofdonderzoeksvraag te beantwoorden, werd een panel regressiemodel met vaste effecten uitgevoerd, om rekening te houden met het feit dat de persoonlijke kenmerken niet variëren over de drie metingen van de gebruikerservaring. Dit model had geen statistisch significante variabelen. Over het algemeen kan worden geconcludeerd dat virtual reality met eye-tracking mogelijkheden een veelbelovende methode is om gebruikerservaring te analyseren en kwantificeren.

Niettemin zijn er ook enkele beperkingen aan dergelijke experimenten. Het zicht in de HMD is beperkt in vergelijking met het zicht in de echte wereld. Daarnaast vertalen de gemaakte bewegingen zich niet volledig naar de bewegingen in VR, wat een soort van vervorming en/of vertraging in het zicht veroorzaakt. Door het ontwerp en het uitgevoerde bestand te optimaliseren, kunnen de vertragingen verminderen.

De antwoorden op de open en interviewvragen kwamen in zekere mate overeen met de positieanalyse. De eye-tracking gegevens konden meer diepgaande inzichten toevoegen in hoe de deelnemers hun omgeving en ervaringen verwerken. De deelnemers vonden het leuk om volledig ondergedompeld te zijn in de omgeving, dat de experimenten een verkennend karakter hadden met veel bewegingsvrijheid.

## Abstract

Urbanisation leads to the development of high-rise environments, as densification is often preferred over expansion. This poses risks to the well-being of the users of these areas. Nowadays, urban studies are more focussed on the relation between human perception and spatial characteristics, which allow researchers to gain more insight into these relations. This research aims to explore the interaction between humans and their environment, including conscious and unconscious processes, within immersive virtual environments (IVEs) using eye-tracking technology.

Whilst eye-tracking research traditionally emphasizes participant gaze, this study aims to gain insight into how individuals perceive their surroundings. The eye-tracking data in a controlled environment, combined with the more traditional survey questions, could lead to insights on how the built environment influences user's emotional states and social behaviours. Additionally, this research intends to provide more insights for designing more attractive high-rise environments by studying the experience of users of high-rise areas using immersive virtual reality and eye-tracking technology.

A virtual reality experiment was designed, presenting participants with various models featuring attributes known to influence user-experience, such as building height and greenery presence. Thirty-two participants visited three models each, and after each model they were asked to answer questions on their user-experience. During their visit to each model, data on their positions, rotations, and interactions of their view with objects of interest were logged into csv files. These datasets were analysed using MATLAB to create plots and heatmaps. From the different datasets, it can be concluded that the answers given to the interview and survey questions correspond to the behaviour shown in the VR experiments. Additionally, the study explores different methods to eye-tracking observations.

This research contributes to both urban studies and eye-tracking methodology, offering an approach to quantifying user-experience in high-rise environments. By integrating immersive virtual reality and eye-tracking with a questionnaire, a comprehensive understanding of user interactions and preferences can be achieved, informing future urban design strategies aimed at enhancing user well-being and satisfaction.

## Keywords

Immersive Virtual Environment, User-experience, Eye-Tracking, Built Environment, Virtual Reality (VR) Experiment

# Glossary

| Term | ***Definition*** |
|---|---|
| *High-rise buildings* | Buildings taller than 70 meters |
| *IVE* | Immersive Virtual Environment: Computer-generated simulations that immerse users in a virtual environment |
| *HMD* | Head mounted display: A device that is put on the head which displays a virtual environment, immersing the person in the virtual world and blocking out the real world |
| *VR* | Virtual reality |
| *Eye-tracking* | A method used to monitor and record the eye-movements and view of individuals |
| *Gaze* | The direction or focus of a person's eyes |
| *User-Experience* | A positive or negative value which describes the combination of the emotions: safety, comfort, annoyance and happiness at a given moment in time |
| *Emotions* | momentary mental states which are triggered by elements of the environment, whereas experiences last a period of time, Varying from seconds to hours |
| *ANOVA* | Analysis of variances |

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# 1. Introduction

Cities are growing, and forecasts predict that two thirds of the world's population will live in a city by 2050 (Bele & Wasade, 2016). This urbanisation leads to the development of high-rise environments, as densification is often preferred over expansion. In the Netherlands buildings that are taller than 70 metres are considered high-rise (Bouwbesluit, 2012). Urbanisation and the development of high-rise environments pose risks to the well-being of the users of these areas (Resch et al., 2020; Spanjar & Suurenbroek, 2020). Specifically, high-rise environments have a negative effect on the restorativeness of its users, trigger stress responses and are associated with higher risks of geriatric depression (Ho et al., 2017; Spanjar & Suurenbroek, 2020). Additionally, tall residential buildings contribute to social isolation, as they lack human scale (Olszewska-Guizzo et al., 2018). Therefore, it has become of increasing importance to design and develop healthy high-rise environments, which take the interaction with, and effect on its users into account (Fathi et al., 2020; Fu et al., 2021; Resch et al., 2020; Spanjar & Suurenbroek, 2020; Weijs-Perrée et al., 2020).

Traditionally, cities are researched focussing on its physical aspects, rather than the social processes (Resch et al., 2020). Nowadays, urban studies are more focussed on the relation between human perception and spatial characteristics (Fu et al., 2021). User-centred research approaches on the built environment allow researchers to gain more insight into these relations. These insights can then be used to plan and design more attractive cities, which service citizens' needs and contribute to regeneration of urban spaces, avoiding deterioration. Moreover, they could identify deficiencies in the design that experts have overlooked. However, especially with the development of dense, high-rise environments, user-experience has received limited research attention (Paine et al., 2021).

## 1.1 Scope

User-experience is related to the perception and engagement of individuals moving in the built environment and the characteristics of these buildings (Hollander et al., 2021). It is a topic that belongs to the research field of (environmental) psychology and is often split into perception, cognition and emotions, and studies mainly focus on one of the three elements. Emotions are defined as momentary mental states which are triggered by elements of the environment, whereas experiences last a period of time, varying from seconds to hours. In research on user-experience in the built environment, a distinction between studies focusing on perceptual and cognitive processes, or on emotional appraisal is present. These studies either focus on how the participants process the information or on how they respond to it (Houtkamp, 2012). Different aspects have been studied regarding user-experience in the built environment, such as the effect of soundscape (Krzywicka & Byrka, 2020; Tan et al., 2022) and visual stimuli (Fathi et al., 2020; Llinares et al., 2020), and if the built environment influences mental state (Evans, 2003; Ho et al., 2017; Olszewska-Guizzo et al., 2018).

One method to study user-experience is by conducting qualitative interviews, as (Pykett et al., 2020) used in their study on stress responses to environmental triggers. However, there are some disadvantages to this method. Cognitive biases or memory errors could influence the outcome's reliability, as these interviews are often retrospective (Resch et al., 2020). In neuroarchitecture, biosensors are used to study user-experience on design principles in the built environment (Spanjar & Suurenbroek, 2020). As individuals move through the urban space, their environment, and thus their perception, changes over time. This perception is heavily influenced by the street interfaces (Al Mushayt et al., 2021). Physical responses, such as changes in heart rate and skin conductance, are measurable indicators for human experience. Whereas interviews and questionnaires are retrospective reports, biometric tools can report physical responses real-time (Pykett et al., 2020; Resch et al., 2020). Biometric data that could be used are, amongst others, skin conductance levels, heart rate and cortisol levels, which can indicate stress, and electroencephalography monitors and post-hoc functional Magnetic Resonance Imaging which measure brain activity (Pykett et al., 2020). The environment is experienced through human senses, of which vision provides 87% of the information (Tao et al., 2022). Eye-tracking technology can be used to quantify the views of the individual and teaches how the eye processes stimuli (Amati et al., 2019; Hollander et al., 2020). Combining these tools links the physical responses to the visual stimuli, which could create useful insights in the perception of urban spaces (Hollander et al., 2021; Krzywicka & Byrka, 2020; Resch et al., 2020).

There is an increasing interest in evidence-based interventions in the built environment and more research is needed to create understanding on the interaction between human and environment, including both conscious and unconscious processes (Hollander et al., 2021; Llinares et al., 2020). In order to measure this interaction properly, the context in which the experiments take place needs to be controlled (Pykett et al., 2020). If there are too many variables in the context, it is difficult to understand which function as a trigger. By creating representations of the built environment, e.g., using photos or virtual reality (VR) technology, these variables can be controlled.

In eye-tracking research the focus is mainly on what the participants are looking at, rather than how they perceive the objects they are looking at. Biosensors measuring brain activity, skin conductance, blood pressure or heartbeat are less popular methods, and only a few combine eye-tracking with some of these biosensors, whilst these sensors provide valuable data for quantifying physical responses which are related to user-experience. As mentioned previously, there are research opportunities for studying user-experience in high-rise environments. Thus, a research gap can be identified for both the environment in which the study is conducted, as well as using eye-tracking techniques for measuring user-experience.

### 1.2 Research Questions

This research aims to address this research gap and to provide more insights for designing more attractive high-rise environments by studying the experience of users of high-rise areas, answering the main research question:

*What characteristics of high-rise areas influence the user-experience, when modelled in an immersive virtual environment and using eye-tracking observations?*

In order to answer this main research question, there are several sub-questions of relevance. These sub-questions are formulated as follows:

1. How can user-experience be defined?
2. How do people observe (virtual) environments? And how does observation relate to user-experience in the built environment?

3. What characteristics of the built environment have been found to influence the user-experience? How can these be translated into high-rise environments?
4. What is eye-tracking and how could it be used to measure the perception of high-rise environments?
5. How can the eye-tracking data focusing characteristics of high-rise environments be related to user-experience?
6. What advice can be given to researchers in the built environment on this topic?

### 1.3 Relevance

The outcomes of this research will be relevant for policymakers, urban planners, managers, and designers, as it helps them designing urban areas where there is a match between the design intent and user's experience and perception. Knowledge on how the built environment influences user's emotional states, will provide insight on their reasoning, decision-making and social behaviours, amongst others (Daly et al., 2016).

Besides, it contributes to the application of eye-tracking technology in urban research and suggests a novel approach to measure and quantify user-experience. The current number of studies on eye-tracking and user-experience in the built environment is still limited. If the knowledge on this topic expands, it could be applied to improve individual design processes in the future (Al Mushayt et al., 2021; Spanjar & Suurenbroek, 2020).

### 1.4 Research Design

The next chapters will focus on answering the research question and sub-questions. Chapter 2 will provide a literature review on user-experience in public space and methods on measing the experience. This literature review will provide the answer to sub-questions 1 to 3. Chapter 3 will elaborate on sub-question 4, in which the chosen method and research approach of this study will be described, as well as the data management and ethics of the experiment. Chapter 4 will go deeper into the expected results and the in the last chapter, Chapter 5, the conclusion and discussion will be elaborated. The overall research design is visualised in Figure 1.

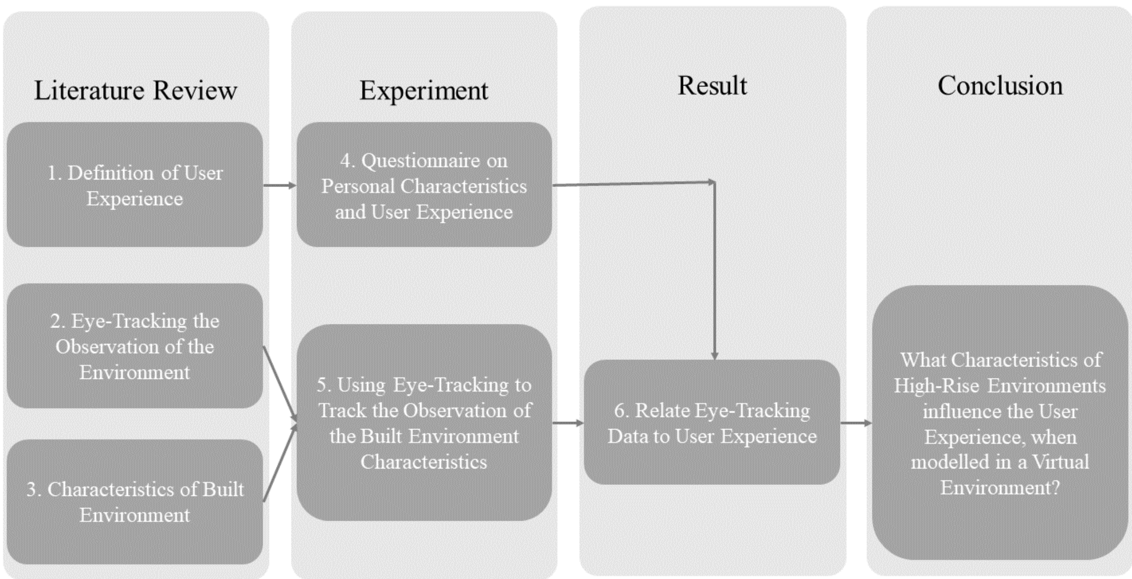


*Figure 1 Visual Representation of the Overall Research Design*

# 2. Literature review

*This chapter provides a literature review to answer sub-questions 1 to 4 and lay the foundation for the experiments described in Chapter 3. Firstly, the chapter will present the Stimulus-Organism-Response model which presents an empirical framework for research in user-experience. Secondly, the effect of building characteristics on user-experience will be studied. Lastly, different applications of eye-tracking and other body sensor network techniques will be explored. The chapter will be concluded with a conceptual model.*

## 2.1 User-experience in the Built Environment

As mentioned in the introduction, user-experience could be defined as the combination of perception and cognition of elements of the environment and the emotions they trigger, in a certain period varying from seconds to hours. In order to understand this process in a virtual reality experiment, it is necessary to understand how participants respond to virtual environments. The Stimulus-Organism-Response model provides a framework for this understanding.

### 2.1.1 Stimulus-Organism-Response Model

The Stimulus-Organism-Response model, as developed by Mehrabian & Russell (1974), proposes a framework to describe the relation between users and their environment. It theorises that individuals respond emotionally to their environment (stimulus) and they have characteristic emotions based on their personality. Then the individual processes the stimuli, consciously or unconsciously. The three main emotional responses to their environment are defined as pleasure (degree of happiness experienced), arousal (degree of excitement experienced) and dominance (degree of freedom to act experienced). These three emotions each form an axis in a three-dimensional model. The score an individual assigns to each of the three main emotions, pinpoints a place in the model, which corresponds to a more complex emotion. This process of internal evaluation is called the organism. Based on these three initial emotional responses, the individuals will show avoidance or approach behaviour (response), as visualised in Figure 2.

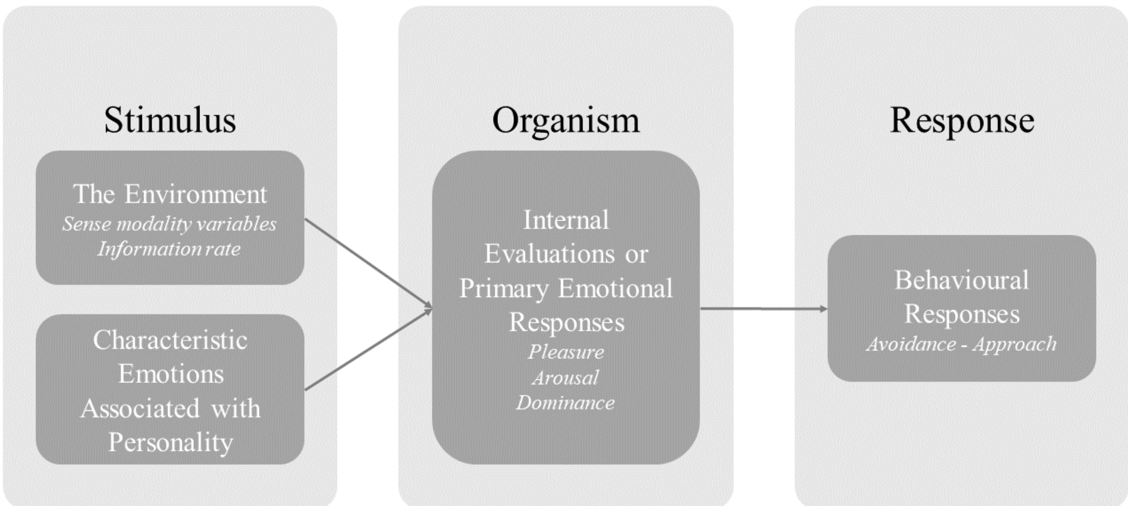


*Figure 2 The Stimulus-Organism-Response Model, as developed by Mehrabian & Russell in 1974*

There have been several adaptations of Mehrabian & Russel's model depending on the context in which it is used. (Bitner, 1992) converted this model to the context of services capes, which formed the basis for Houtkamp's (2012) adaptation applied to her research on affective appraisal of virtual environments. Houtkamp's (2012) framework is visualised in Figure 3 and will form the base framework for this research.

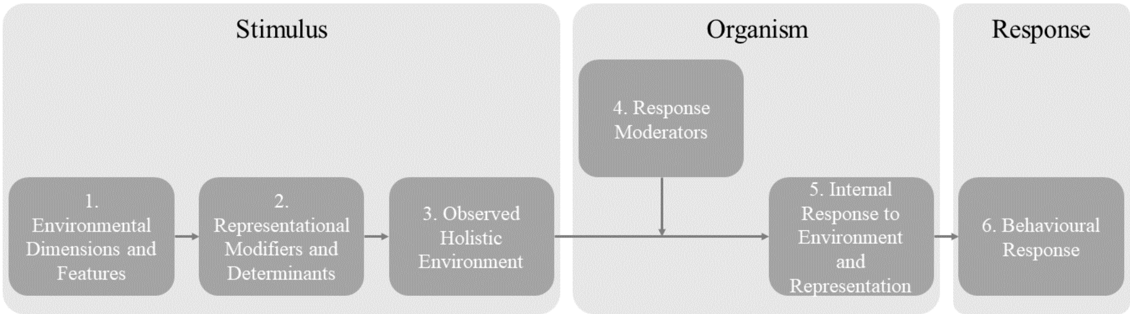


*Figure 3 Simplified Framework as used by Houtkamp (2012) for studying the response to virtual environments*

When comparing Figure 2 and Figure 3, several differences can be recognised. First of all, Mehrabian & Russel's framework identifies the stimulus as the environment and characteristic emotions associated with personality, which are not present in the framework as used by Houtkamp. Instead, the environment is split in three categories: environmental dimensions and features, representational modifiers and determinants, and observed holistic environment. Personality is included in the box called response moderators. Other response moderators are for example experience and mood.

Bitner (1992) stated that, based on her literature review, the environment is composed of three dimensions: the ambient conditions, spatial layout and functionality, and signs, symbols, and artifacts. These are integrated in square 1. Environmental Dimensions and Features, in Figure 3. Houtkamp (2012) used the same three dimensions in her framework, to categorise the relevant determinants in affective appraisal. A virtual environment is a representation of reality, therefore the determinants are modified by the features of the virtual representation. Though the virtual environment exists of separate determinants, it is often assumed that people observe it as a whole. Additionally, the observation of the holistic environment might be influenced by memories of references (Imamoglu, 2009).

When the stimulus is observed, the response moderators come into play. The individual's perception is influenced by how they feel at that moment and their personality, as well as with what task they are visiting the environment (Houtkamp, 2012). The observation then changes to a perception. The individual could experience a change in mood, as an internal response to the environment. This internal response could then result in a behavioural response, such as the approach/avoidance behaviour Mehrabian & Russel described.

### 2.1.2 Theories of User-experience

In order to measure user-experience, it is necessary to identify the possible internal responses. An individual person could experience many emotions and two classification approaches have been dominant in research: discrete and dimensional (Jacob-Dazarola et al., 2016). The discrete approach implies that facial expressions could be used to distinguish between different emotions, whilst the dimensional approach implies that valence, arousal, and tension are the three main emotions, based on which other emotions can be described.

This dimensional approach corresponds with the pleasure, arousal, and dominance model, as proposed by Mehrabian & Russell (1974). These emotions could be identified using a semantic differential consisting of 40 adjectives, which describe the qualities of an environment (Russell & Pratt, 1980). A disadvantage of this approach is that individuals often find it difficult to put their emotional experiences into words, and it is only possible to do so if they are conscious of the emotion they are experiencing (Houtkamp, 2012).

According to Ekman (1999) all emotions are related to a set of basic emotions, namely: anger, joy, fear, disgust, sadness, and surprise. This theory is referred to as the discrete approach. Zeile et al. (2015) used this approach to identify emotional responses to urban environments. Olszewska-Guizzo et al. (2018) studied emotional responses in an EEG experiment and found activity in areas of the brain which related to pleasure, joy, relaxation, fear, disgust, some of which thus correspond to the earlier identified basic emotions. When looking at studies regarding the user-experience and emotions in the built environment, other dimensions of user-experience have been applied as well. Birenboim et al. (2021) used momentary social well-being to describe the individual's emotion at a certain moment in time. According to their research, it could be split into four main emotional states: sense of security, comfort, happiness, and annoyance. These have been applied in other studies regarding user-experience in the built environment as well (Liao et al., 2022; Weijs-Perrée et al., 2020; Zhao et al., 2022). By limiting the number of emotions, the cognitive is reduced. Therefore, this research will focus on sense of security, comfort, happiness, and annoyance. Zhao, et al. (2022) concluded that these four emotions could be combined to the single attribute of experience, which could be negative or positive, as the factor analysis showed a correlation between the dimensions and the internal consistency was relatively high.

Another emotional state that multiple studies looked into is stress (e.g. Birenboim et al., 2021; Pykett et al., 2020; Van den Berg et al., 2016). Stress-responses can be accurately measured by biosensors during the experiment, whereas emotions are often reported with retrospective interviews (Resch et al., 2020). However, tracking the occurrence of stress-responses does not provide information about the user-experience, it solely indicates that an internal response is present (Pykett et al., 2020).

### 2.1.3 Characteristics of the Built Environment

Previous studies in environmental psychology have already provided some insight into the relation between characteristics of the built environment and user-experience in different contexts. These relations will be explored, the relevant characteristics correspond with *1. Environmental Dimensions and Features* of the Stimulus-Organism-Response model and will be added to the conceptual model.

One of these studies is conducted by Ho, et al. (2017), and focussed on the relation between different urban densities and geriatric depression risk. A depressed mental state was found to be related to a negative experience of the built environment. One of their findings was that in high-density cities, presence of greenery did not have a significant effect on the mental state, whereas areas with a lower average building height and a greater variation of building heights did contribute to a lower risk of geriatric depression. High-rise buildings influence people's experience, as they promote anonymity and are linked to higher crime levels, which decreases the feeling of safety (Evans, 2003; Ho et al., 2017; Olszewska-Guizzo et al., 2018). People tend to feel more relaxed in areas where a sense of scale is present, which is disturbed in high-rise environments (Andreani & Sayegh, 2017; Harvey et al., 2015; Olszewska-Guizzo et al., 2018). Harvey et al. (2015) studied the effects of skeletal streetscape design on perceived safety and found that the perceived safety increases when there are more buildings per block of a set length and the buildings are taller.

Other studies did find a relation between green environments and user-experience. Olszewska-Guizzo, et al. (2018) studied participants' brain wave patterns when presented with different views. When participants were presented with more natural views, brainwave patterns related to joy and relaxation were activated. Greenery is often associated with restorativeness (Llinares et al., 2020; Peters & Halleran, 2021; Van den Berg et al., 2016; Zhao et al., 2022). Specifically, grass surfaces, trees and the presence of water are related to positive user-experience (Zhao et al., 2022). Trees provide coverage and were found to have a positive relation to perceived safety (Harvey et al., 2015; Mouratidis, 2019). However, areas with a lot of clustered trees, were perceived as unsafe, especially after dark (Rahm et al., 2021).

Buildings with architectural ornamentations and details were found to be related to a positive user-experience (Van den Berg et al., 2016) , whereas buildings with large blank walls are associated with sadness and decrease the perceived safety (Jansson, 2019; Joglekar et al., 2020). Additionally, buildings with active plinths contribute to the perceived safety (Jansson, 2019). Clear view of the sky relates to the presence of daylight, which contributes to feelings of comfort (Llinares et al., 2020; Peters & Halleran, 2021). Presence of daylight and sufficient street lighting, allows for a clear view of the area. Being able to see the surrounding space and its other users, stimulates feelings of comfort and safety (Evans, 2003; Llinares et al., 2020).

In addition to visual stimuli, other senses, such as smell and sound, could influence the user-experience. Clean or natural smells in urban areas have a positive effect on the feeling of comfort, whereas offensive smells are more likely to trigger annoyance (Weijs-Perrée et al., 2020). The soundscapes could be linked to crowding, presence of nearby vehicles or nature. Noisy environments have a negative effect on the user-experience (Evans, 2003; Krzywicka & Byrka, 2020; Weijs-Perrée et al., 2020), and could even trigger aggressive behaviour (Evans, 2003). Sounds of nature on the other hand, contribute positively to the user-experience (Krzywicka & Byrka, 2020).

CoHeSIVE is a seed-fund project funded by alliance between University of Technology Eindhoven, Utrecht University, and Wageningen University and Research, and recently held a workshop to identify main design attributes for healthy public spaces (CoHeSIVE, 2022a). In the exploratory phase, participants identified attributes that they found influential on health from pictures. The most identified attributes were: presence of trees, presence of canopies, presence of benches, amount of driving cars, monotonous or diverse façades, pavement, or grass surface, signeted or shared paths, and the presence of fountains. During this workshop, it was also found that building height and presence of daylight were related to a feeling of safety.

### 2.1.4 Personal Characteristics

Besides characteristics of the built environment, there are also personal characteristics that influence the user-experience (Zhao et al., 2022). User-experience will be measured in this study by questioning the safety, comfort, annoyance, and happiness of the participants.

One often mentioned personal characteristic is personality, to which different attributes are assigned. Mehrabian & Russell (1974) mentioned in their study that especially arousal-seeking tendencies of an individual are of influence. As the higher the arousal seeking tendency of a person, the more likely they are to have positive experiences at more complex locations or locations where more stimuli are present. This complexity and number of stimuli is related to the building characteristics height of buildings and architectural detailing.

On the other hand, happiness can be predicted by the personality traits extraversion and neuroticism (Birenboim, 2018). Additionally, it is found that individual's daily mood may impact the user-experience, as does their familiarity with the neighbourhood (Birenboim, 2018; Houtkamp, 2012; Peng et al., 2021). Zhao et al. (2022) found that people who lived in denser neighbourhoods had a more positive experience of public spaces. No statistically significant effect of age and gender was found on the momentary experience of public space (Zhao et al., 2022). However, other studies found that older people tend to feel less happy in general, when compared to their younger counterparts (Birenboim, 2018; Weijs-Perrée et al., 2020) and women tend to feel less safe (Llinares et al., 2020).

## 2.2 Measuring User-experience

One of the methods to measure user-experience, is self-report. Retrospective reports provide a low threshold manner to ask about user-experience. However, these self-reports provide limited insight as they are subjected to the respondent's attention, memory, and biases. Therefore, methods that measure user-experience in real time have been gaining more interest, as they provide more insight on the surroundings (Resch et al., 2020).

Eye-tracking and body sensor network (BSN) techniques are examples of different methods to measure user-experience. Several studies have applied these techniques in urban research. However, the methods applied and the research aims vary. In Table 1, a literature summary is provided which describes the research aim and method of different studies using these techniques.

*Table 1 Literature review on the strategies of urban studies investigating interaction between the built environments and its users*

| AUTHORS | RESEARCH AIM | TRACKERS USED | TYPE OF VISUALS | INDOOR/OUTDOOR |
|---|---|---|---|---|
| AMATI ET AL. (2019) | Analyse fascination in urban parks | Eye-Tracking | Video | Outdoor |
| ANDREANI & SAYEGH (2017) | Study route mapping | EEG, Eye-Tracking | On-site | Outdoor |
| BIRENBOIM ET AL. (2021) | Measure participant's enjoyability of the environment | Eye-Tracking | Video | Outdoor |
| BRAZIL ET AL. (2017) | Study cyclist's ability to identify safety hazards | Eye-Tracking | Photo | Outdoor |

| | | | | |
|---|---|---|---|---|
| FRANĚK ET AL. (2019) | Research fixations and duration of fixations in different environments | Eye-Tracking | Photo | Outdoor |
| HOLLANDER ET AL. (2021) | Study unconscious responses to façades | Eye-Tracking | Photo | Outdoor |
| HOLLANDER ET AL. (2020) | Study human responses to neighbourhood design | Eye-Tracking | On-Site | Outdoor |
| LLINARES ET AL. (2020) | Study pedestrian's perception of safety on street crosses | EEG, Self-Evaluation | Photo | Outdoor |
| OLSZEWSKA-GUIZZO ET AL. (2018) | Study the influence of window views on brain activity | EEG | Photo | Indoor |
| RESCH ET AL. (2020) | Study stress in outdoor environments | ST, GSR, ECG, HR, HRV, BVP, EMG | Video | Outdoor |
| RUPI & KRIZEK (2019) | Study how cyclists perceive the environment | Eye-Tracking | On-Site | Outdoor |
| SAYEGH ET AL. (2015) | Measuring gaze, attention, and memory in the built environment | Eye-Tracking | On-Site | Outdoor |
| SIMPSON ET AL. (2019) | Study visual engagement with urban street edges | Eye-Tracking | On-Site | Outdoor |
| SPANJAR & SUURENBROEK (2020) | Measuring visual experience in high-rise environments | Eye-Tracking | Photo | Outdoor |
| ZOU & ERGAN (2019) | Study restorativeness of environments | EEG, GSR, Eye-Tracking | Photo | Outdoor |

From Table 1, it can be concluded that eye-tracking is already used in urban research, especially in combination with photos of outdoor environments. Most of these studies focussed on what the participants were looking at, rather than the effect of what they were looking at on their experience. Additionally, studies conducting eye-tracking experiments using Immersive VR are even more limited.

Eye-tracking technology describes the eye movements using different units of measure. The most obvious unit of measure is gaze points. The gaze points describe all the points the eye looked at during measurement. Next to gaze points, fixations (what points was focussed on), scan paths (the sequence of gaze points), the duration of fixation and the saccades (movement to the next fixation) are of interest, as they provide insight in the cognitive processing of the individual (Hollander et al., 2019; Kiefer et al., 2017; Spanjar & Suurenbroek, 2020; Ugwitz et al., 2022). Heat maps are used to visualise the intensity of fixations around different areas of the viewed visual, if a study is focussing on specific attributes of the visual, so-called areas of interest can be identified beforehand (Hollander et al., 2021; Simpson, Freeth, et al., 2019).

When looking at what attracts the eye of the participant, several attributes can be recognised. Spanjar & Suurenbroek (2020) studied the eye-tracking patterns when presented photos of high-rise environments from a street point of view. They found that participants attraction was drawn to people in the photos, as well as readable object such as signs (Hollander et al., 2020; Spanjar & Suurenbroek, 2020). Fixations were recognised on the active ground floor of the buildings and in the façade detailing (Al Mushayt et al., 2021; Hollander et al., 2020;

Spanjar & Suurenbroek, 2020). The study by Van den Berg et al. (2016) supports the finding that buildings with a higher level of façade detailing are viewed longer.

In case of eye-tracking in a dynamic environment, it is found that the gaze of the participant will move to the objects in their path, before the participant will look at the buildings (Rudenko et al., 2021). They are more visually engaged with the street edge and ground floor at the side they are walking, than the other side of the street or higher floors (Simpson, Thwaites, et al., 2019).

## 2.3 Conclusion

In conclusion, this chapter looked into the stimulus-response model, the definition of user-experience, what characteristics of the built environment possibly have an influence on the user-experience and different methods to measure the user-experience.

The stimulus-organism response model proposed a framework for understanding the relation between the user and the environment. User-experience is related to the perception and engagement of individuals moving in the built environment and the characteristics of these buildings. There are two dominant theories to describe user-experience: the discrete approach and the dimensional approach. In research of the built environment, on the other hand, user-experience is often measured using the four main emotional states: sense of security, comfort, happiness, and annoyance. This study will focus on these four main emotional states as well. In the literature review it was found that several characteristics of the built environment influence these four main emotions, as well as some personal characteristics. These characteristics have been summarised in Table 2.

*Table 2 Overview of characteristics that influence the user-experience according to the literature*

| *Characteristics of the built environment* | *Personal characteristics* |
|---|---|
| *Overall building height* | Age |
| *Variation of building height* | Gender |
| *Sense of scale* | Urbanisation of living environment |
| *View of the sky* | Frequency of visits to high-rise environments |
| *Presence of daylight* | Personality |
| *Number of buildings per block length* | Mood |
| *Level of architectural detailing* | |
| *Presence of streetlighting* | |
| *Amount of grass* | |
| *Number of trees* | |
| *Clustering of trees* | |
| *Presence of water* | |

User-experience is traditionally studied using self-reports and photos or videos. However, these methods have limitations as the freedom of movement is limited and due to the retrospective nature of self-reports the data gathered might be biased by outside factors. In built environment research evidence-based interventions are gaining more popularity. This means that there is an increasing interest in using techniques, such as eye-tracking, to gather user-experience data real time. Eye-tracking technologies are able to track the eye movement, and gather data about gaze points, scan paths, duration of fixations, and saccades. This data can be visualised using heat maps and provides insights into, amongst others, the cognitive processing and fascination of the viewer. When combined with the traditional questionnaire, it could be a helpful tool to further quantify the user-experience. Something to consider when studying an individual's gaze is that it is often drawn to other people or signs, and to potential obstacles in their walking path before it moves to the plinth and detailing of the buildings in their surroundings.

### 2.4 Conceptual Model

Based on the literature review, a conceptual model can be created, which is based on the stimulus-organism-response model, as visualised in Figure 4.

The holistic environment the participant will observe, consists of the KnoopXL project in Eindhoven (CoHeSIVE, 2022), and the modifications made to the model based on the literature review. The steps of the stimulus-organism response model are visualised in dark grey, below these are the different attributes are assigned in light grey squares.

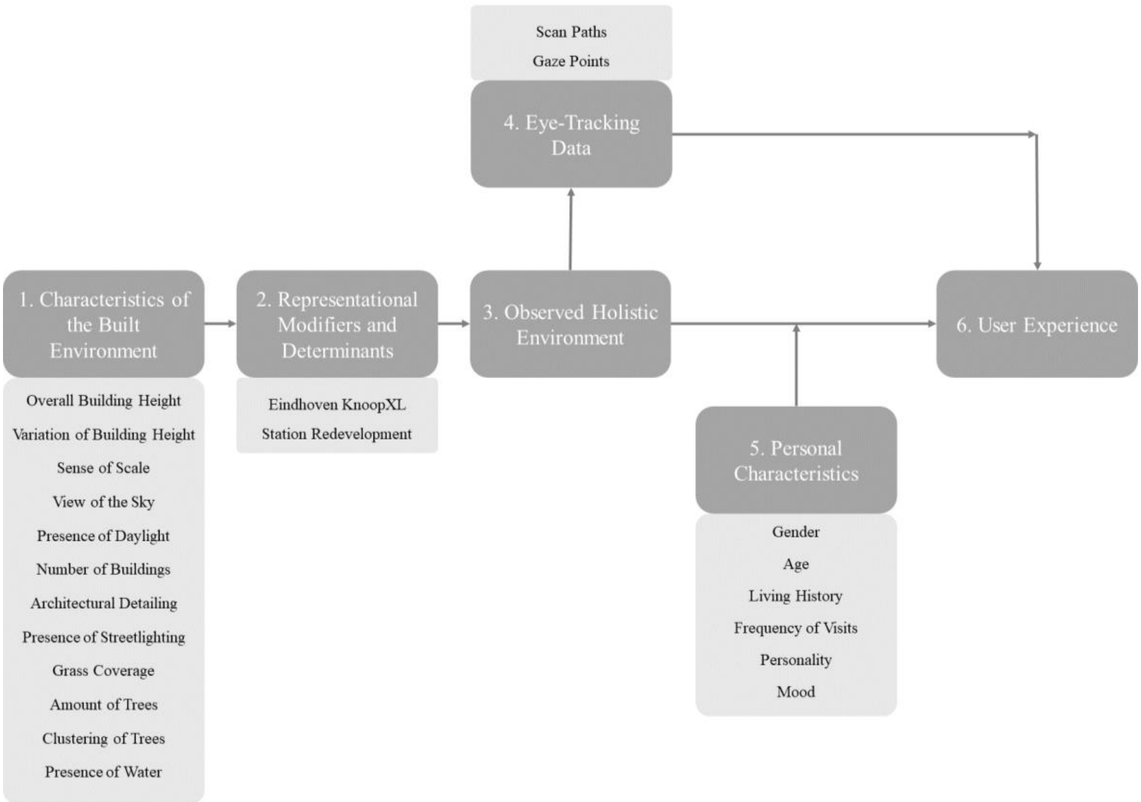


*Figure 4 Conceptual Model*

# 3. Research approach

*This chapter will answer sub question 5 by designing an experiment in Immersive Virtual Reality. The process of data collection and the reliability and validity of the data will be discussed. The last section of this chapter will describe the steps taken in order to set-up and conduct the experiments, and how the outcomes of the experiments will be processed.*

## 3.1 Method Description

To analyse the influence of characteristics of high-rise environments on the user-experience, experiments in virtual reality will be conducted and a questionnaire will be completed. This means that data will be collected using quantitative methods. This sub-chapter will further explain the experiment and supporting questionnaire.

Not all attributes from the conceptual model, introduced in Chapter 2.4, are included in the VR models. It is chosen to leave out the attributes *sense of scale, view of the sky* and *presence of daylight*, as there is a possibility they are correlated to the *building height*. This makes it difficult to separately assign attribute levels for these attributes, as well as measure them separate from the building height. Next to that, the *amount of streetlighting* will not be varied, as the experiment will take place in a daylight setting. The model is based on the redevelopment project of KnoopXL in Eindhoven, which has several freestanding towers, instead of building blocks. Therefore, the *number of buildings per block* is limited. The architecture of the KnoopXL development is used in the models, thus the *level of architectural detailing* will not be included as an attribute with varying attribute levels. However, a distinction will be made between a blank façade and an active façade that mirrors the sky. Figure 5 provides an overview of the characteristics of the built environment varied in the VR models.

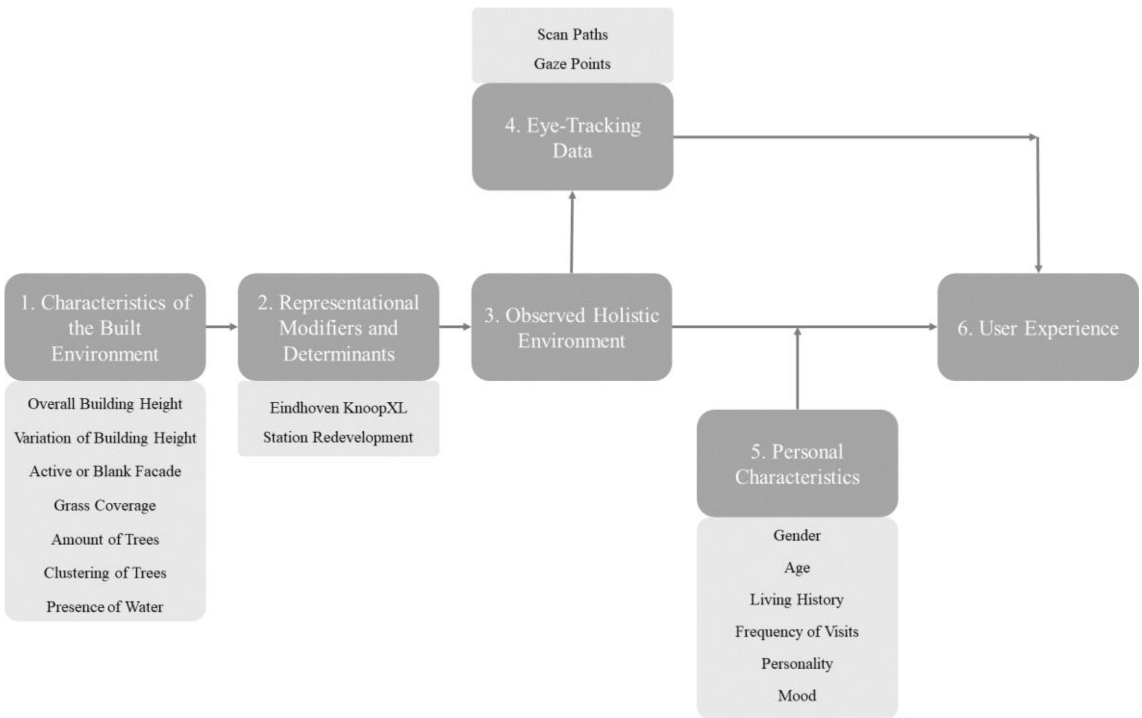


*Figure 5 Conceptual Model with only attributes varied in the VR models*

### 3.1.1 The SketchUp Model

During the experiment, a SketchUp model of the KnoopXL redevelopment project in Eindhoven (CoHeSIVE, 2022) will be visited. KnoopXL is the name of a large-scale redevelopment around the central train station area in the inner city of Eindhoven. The modelled area exists of three high-rise towers on the west side, to high-rise towers on the east side and the station with park in between. The simulated area is visualised in Figure 6.

*Figure 6 Simulated environment of the KnoopXL redevelopment*

Attribute levels are assigned to the characteristics of the built environment as identified in Chapter 2. Table 3 presents an overview of the attributes and corresponding attribute levels which will be varied in the different models. The number of attribute levels has been limited to two level each attribute, to simplify the experiment.

*Table 3 Overview of attributes and attribute levels*

| ***Attributes*** | ***Level 0*** | ***Level 1*** |
|---|---|---|
| *Overall building height* | Skyscraper (approximately 180m) | High-rise (approximately 90m) |
| Variation *in building height* | Differences in building height | Similar building heights |
| *Façade* | Active plinth (mirrored façade) | Blind wall |
| *Grass coverage* | 50% | 0% |
| *Number of trees* | Many | Few |
| Clustering *of trees* | Clustering | Spread |
| *Presence of water* | Fountains | None |

With this number of attributes and attribute levels, it is possible to create a total of 128 different models. Orthogonal experimental design is used to reduce the number of combinations, thus the number of different models. In an orthogonal experimental design, each attribute level will occur an equal number of times over the combinations, whilst avoiding correlation between the different combinations (Hensher et al., 2015). SPSS was used to determine orthogonality, which resulted in 8 different models. The attribute levels per model are specified in Table 4.

*Table 4 Overview of Combinations in  orthogonal design*

| ***Model Number*** | **Building Height** | **Height Variation** | **Façade** | **Grass** | **Trees** | **Clustering Trees** | **Water** |
|---|---|---|---|---|---|---|---|
| *1* | Skyscraper | Differences | Active Plinth | 0% | Few | Spread | None |
| *2* | Skyscraper | Similar | Blind Wall | 50% | Few | Spread | Fountains |
| *3* | High-Rise | Similar | Active Plinth | 0% | Many | Spread | Fountains |
| *4* | Skyscraper | Differences | Active Plinth | 50% | Many | Clustering | Fountains |
| *5* | High-Rise | Differences | Blind Wall | 0% | Few | Clustering | Fountains |
| *6* | Skyscraper | Similar | Blind Wall | 0% | Many | Clustering | None |
| *7* | High-Rise | Similar | Active Plinth | 50% | Few | Clustering | None |
| *8* | High-Rise | Differences | Blind Wall | 50% | Many | Spread | None |

The SketchUp model of CoHeSIVE (2022) was used as basic model and the different attribute levels were varied to create the different models.

### 3.1.2 The Unity Model

After the 8 different models were created in SketchUp, there were added to Unity, where the VR features were built in. The equipment used during the VR experiment exists out of the HTC Vive Pro VR glasses with Tobii eye-tracking technology and a designated area in the lab of 4 meters by 5 meters where the participants can walk freely within the VR model. A photo of the researcher in the setup is included in Figure 7. The setup is connected to a PC to run the VR model. The hardware and software details are summarised in Table 5.

*Figure 7 Researcher using VR Setup*

*Table 5 Overview of Hardware and software Details*

| ITEM | | SPECIFICATION |
|---|---|---|
| **VR HEAD-MOUNTED DISPLAY (HMD)** (HTC, 2022) | Screen | Dual OLED 3.5" diagonal |
| | Resolution | 140 x 1600 pixels per eye (2880 x 1600 pixels combined) |
| | Refresh Rate | 90 Hz |
| | Field of View | 110 degrees |
| | Interface | Bluetooth, USB-C |
| | Sensors | SteamVR tracking |
| | | G-sensor |
| | | Gyroscope |
| | | Proximity |
| | | Eye Comfort Setting (IPD) |
| **SOFTWARE** | HTC Vive Pro Eye Setup | |
| | HTC SDK for Eye-Tracking | SRanipal Version 1.3.6.8 |
| | SR Runtime | |
| | Steam VR | 1.26 |
| | Unity (VR Design Platform) | 2021.3.19f1 |
| **COMPUTER** | | Intel |
| | CPU | Core i9-9900K |
| | Memory | 32 GB RAM |
| | Graphic | NVIDIA RTX 2070 SUPER |
| | OS | Windows 10 Enterprise |

Creating a new Unity file, the 3D Universal Render Pipeline template was selected, as it offers the highest graphic accuracy. The XR Interaction Toolkit and XR Plug-in management packages are installed. The HTC Vive controllers are then added to the XR Plug-in Management presets as the interaction profile to enable their features.

Next the SketchUp model will be added to the scene. This provides the base for the VR scene. The XR Origin (VR) is added, as it contains a main camera which corresponds to the head-mounted display (HMD), as well as the controllers. To enable transportation, a locomotion system and teleportation provider are added. The route in the experiment will be from the Eindhoven Central Station building to the small square in the middle of the three new buildings in the west. Therefore, a transportation area will be added to the model, as visualised in blue in Figure 8.

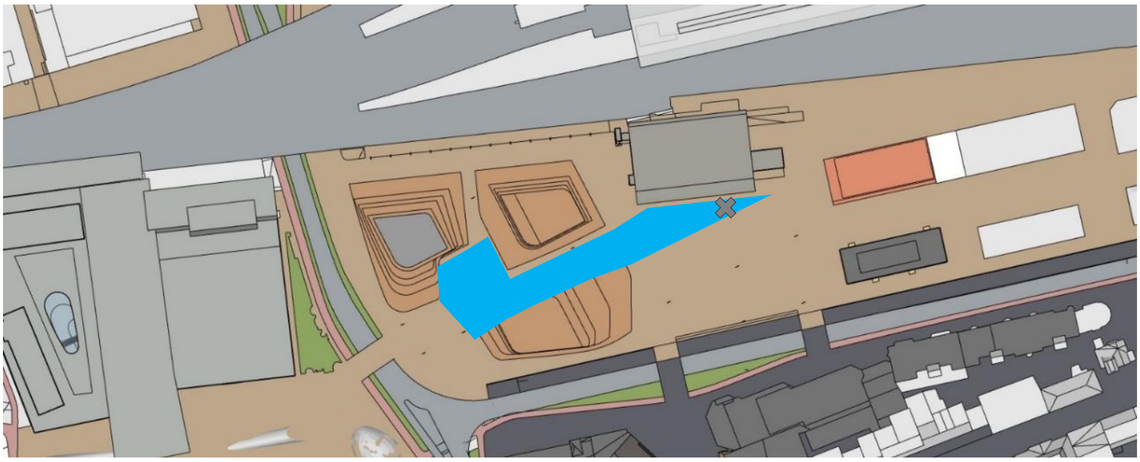

*Figure 8 Transportation Area in the model highlighted in blue.*

Now the basic interaction elements are in place and the participant is able to do some basic transportation. A Unity hierarchy exists out of parent objects and child objects. A child object in Unity can be seen as a subject of the parent and moves relative to it. Another function of a parent object is to group multiple game objects together.

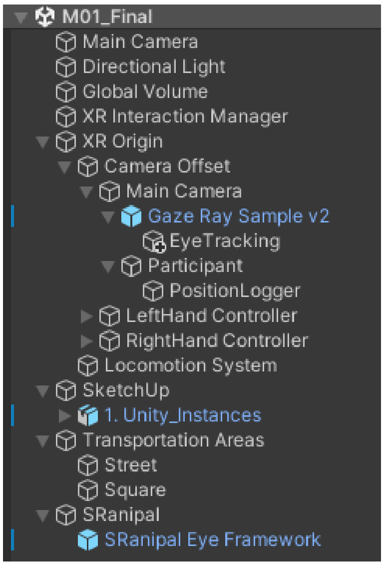


*Figure 9 Unity Hierarchy for models incorporating the HTC SRanipal SDK*

The SRanipal Software Development Kit (SDK) is installed to enable the eye-tracking features. This includes an eye-tracking framework, some sample scripts in C# and the documentation supporting the SDK. Additionally, some C# scripts were written and added to the scene to enable the data collection for this study specifically. The C# scripts are based on the scripts of Clay et al. (2019), Imaoka et al. (2020) and Ugwitz et al. (2022)and adapted to fit the purpose of this study.


*Figure 10 Unity Hierarchy for models incorporating an eye-collider object*

At first, a C# script is created to assign a participant number to each participant that visits a model. This script is assigned to the participant object, which is a child of the Main Camera. Then a C# script is created which saves the position and rotation of the participant in the model every 0.5 seconds. The X-, Y- and Z-coordinates are saved to a csv file, as well as the X-, Y- and Z-rotations. This script incorporates the participant number assigned in the file, to be able to link the data gathered with the survey questions and experiment observations. Lastly, a C# script was created to enable the eye-tracking features of the headset. This script starts the calibration of the eye-tracker each time play-mode is entered. After calibration, the participant will enter the model. Every 0.5 seconds the gaze origin, gaze direction, pupil position and eye-openness are saved to a csv file, together with the participant number. This script is a child of the Main Camera. Additionally, another child is added to the Main Camera, namely the Gaze Ray Sample. This is a prefab from the SRanipal SDK and will cast a ray, which follows the eye movement, into the VR environment, to pinpoint the focus of the participant. Colliders are added to the different attributes of the SketchUp model, so that if the gaze ray interacts with one of the colliders, the time of collision and the attribute it collided with are also saved in the eye-tracking csv file. This allows for an easier analysis of the areas of interest. This leads to the Unity Hierarchy as depicted in Figure 9.

Alternatively, the Unity Hierarchy of Figure 10 was created. This project functions without the SRanipal SDK, due to technical difficulties. The gaze ray feature is replaced by a cylinder which moves relatively to the main camera, thus pinpointing where the camera is looking. The cylinder, thus line of sight of the main camera, is visualised by the red lines in Figure 11. This does not account for the location of the participant's pupil, only for the head movements. This cylinder does not have a physical material in the model, thus cannot be seen by the participant. It does have a collider attached to it, as well as a C# script which logs when the cylinder hits one of the attributes, similar to the script described for the Gaze Ray feature in the previous paragraph. All Unity scripts are attached to Appendix A.

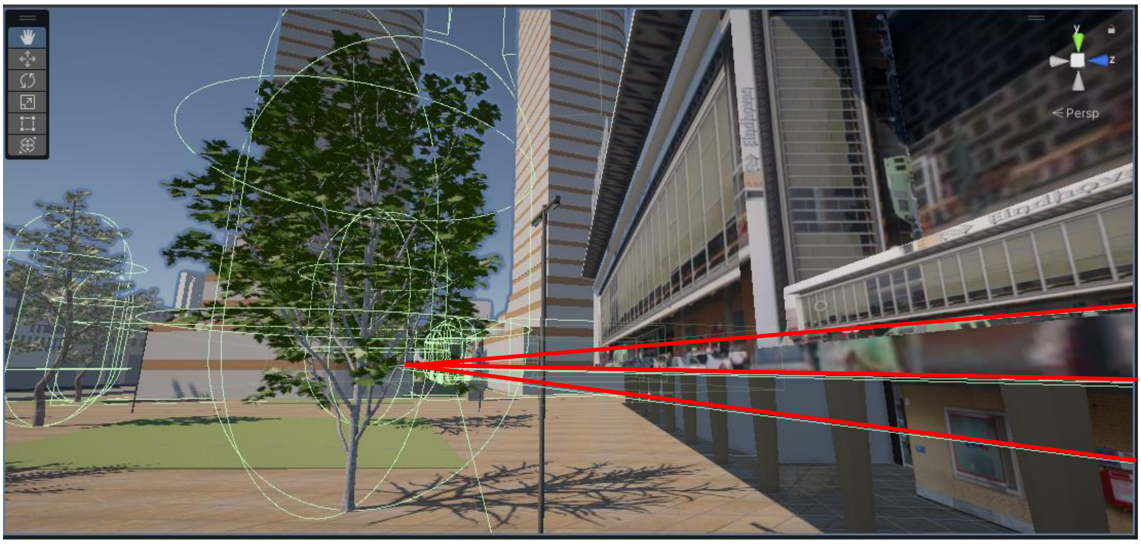


*Figure 11 Screenshot of the Unity model showing the collider objects*

The script for path analysis is included in the models to automatically log the movement through the environments. This allows an easier analysis of common behaviours of the participants based on data points, rather than researcher observations. Next to that, the position data points allow for the rotation of the headset to make sense spatially, as it depicts where in the model the participant was located when looking at a certain direction.

Figures 12 and 13 show the colliders, which are indicated by the green lines, attached to the different attributes of Model 1 to identify the areas of interest. This process is repeated for all attributes in all models.

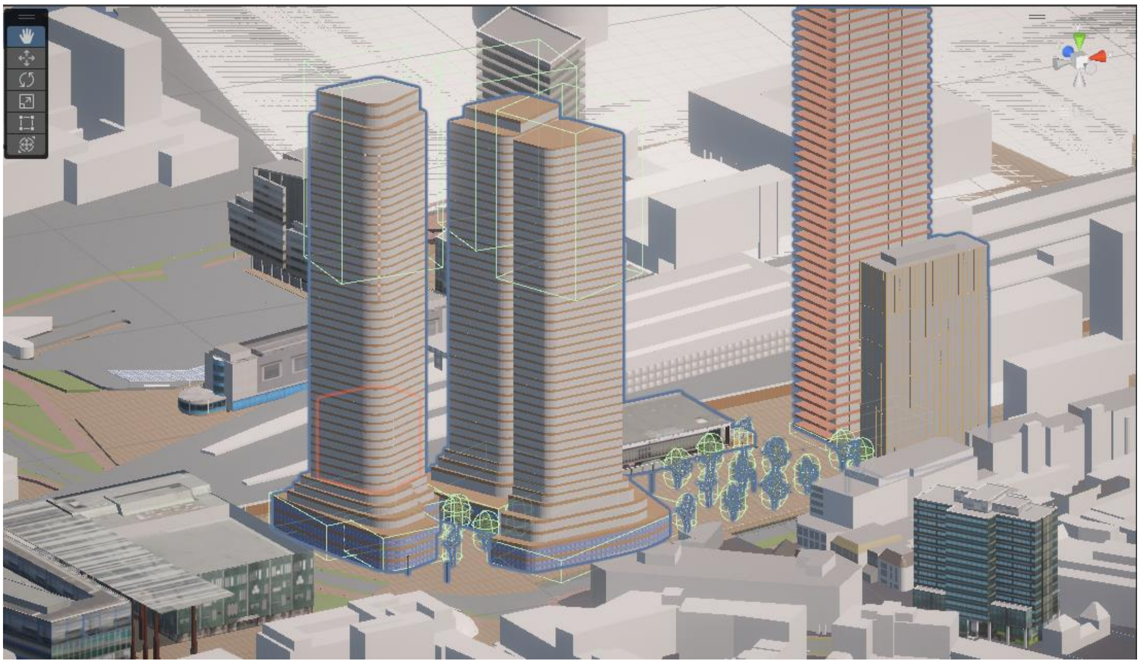
Figure 12 3D view of Model 1 with the green lines indicating the colliders of the different attributes

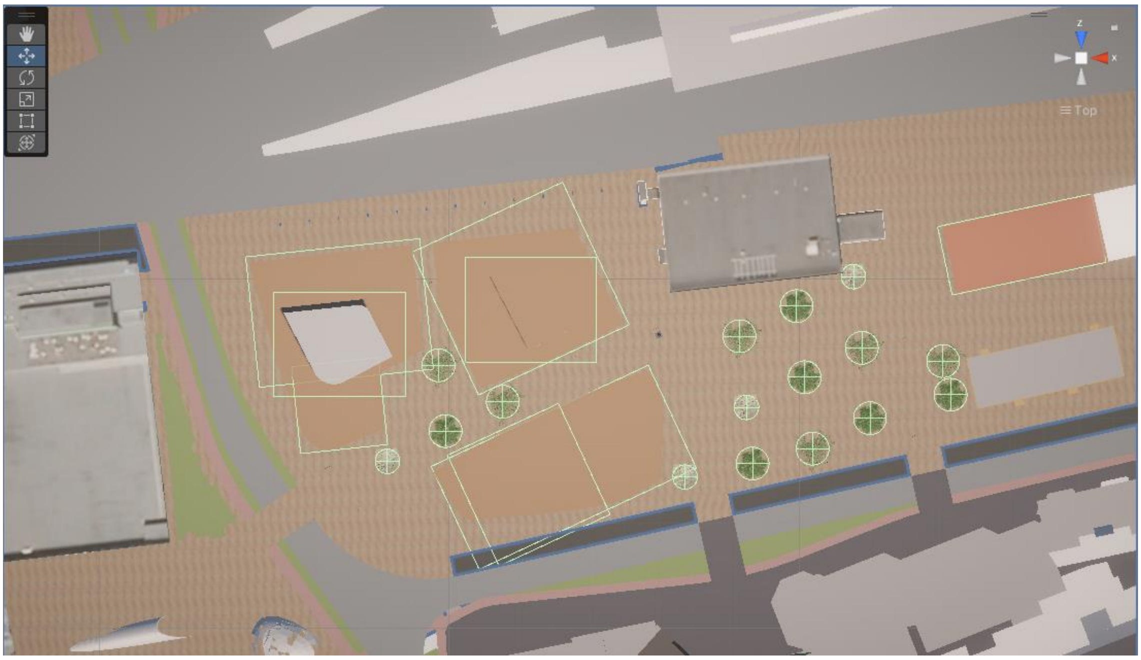

Figure 13 Top view of Model 1 with the green lines indicating the colliders of the different attributes

The participants will not see the colliders around the attributes. The perspective of the participants is captured in Figures 14 till 45 to visualise the differences between the models.

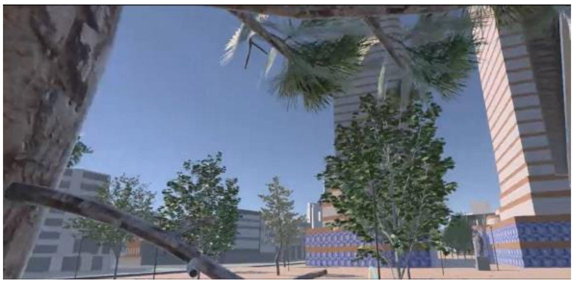
*Figure 14 Model 1 - View from the station*


*Figure 15 Model - View towards the city centre*

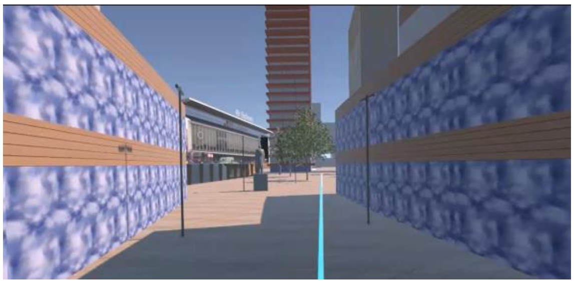

*Figure 16 Model 1 - View towards the station*

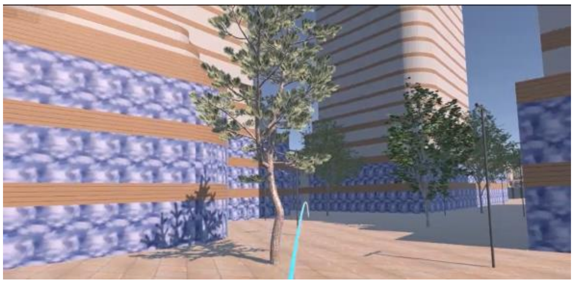

*Figure 17 Model 1 - View on the square in between the redevelopment*

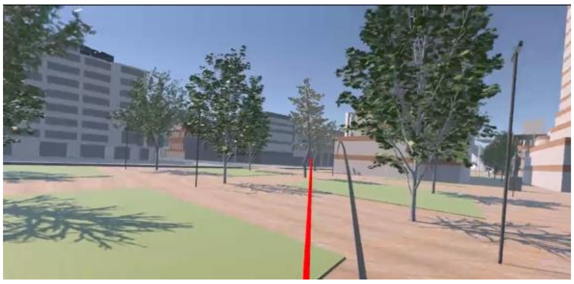

*Figure 18 Model 2 - View on the station square*

*Figure 19 Model 2 - View on building height*

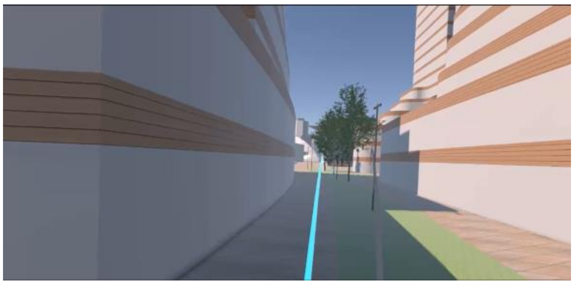

*Figure 20 Model 2 – View towards the city centre*

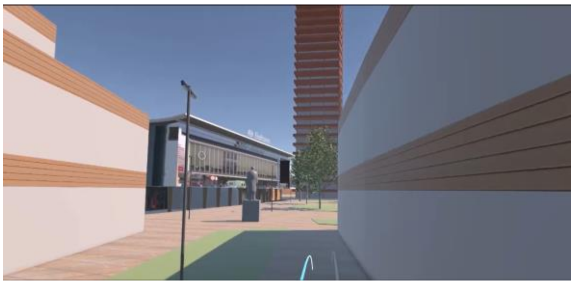

*Figure 21 Model 2 - View towards the station*


*Figure 22 Model 3 - View on building height*

*Figure 23 Model 3 - View on the station square*

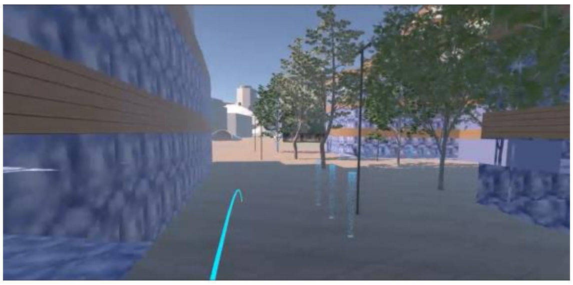

*Figure 24 Model 3 - View towards the city centre*

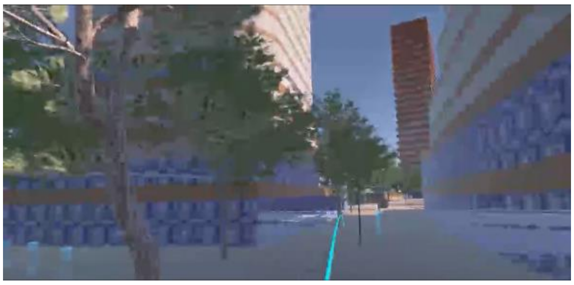

*Figure 25 Model 3 - View towards the station*


*Figure 26 Model 4 - View on building height*


*Figure 27 Model 4 - View on the station square*

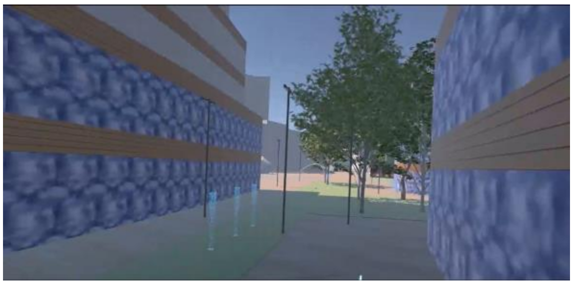
*Figure 28 Model 4 - View towards the city centre*


*Figure 29 Model 4 - View towards the station*


*Figure 30 Model 5 - View on building height*


*Figure 31 Model 5 - View on the station square*

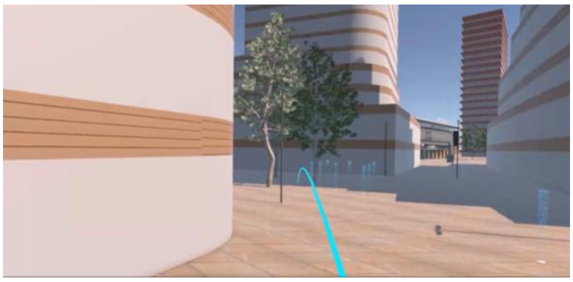
*Figure 32 Model 5 - View on the square in the redevelopment*

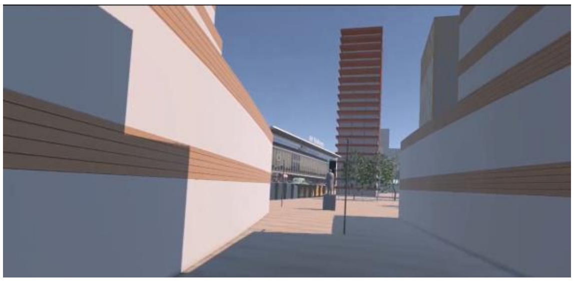
*Figure 33 Model 5 - View towards the station*


*Figure 34 Model 6 - View on building height*

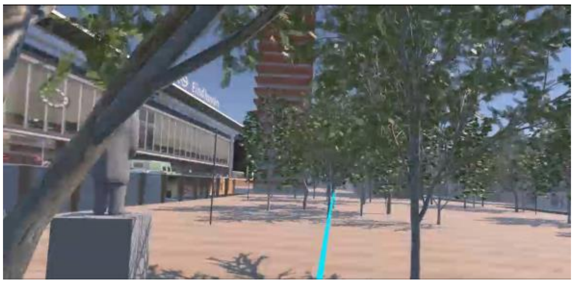
*Figure 35 Model 6 - View on the station square*


*Figure 36 Model 6 - View towards the city centre*


*Figure 37 Model 6 - View on the square in the redevelopment*


*Figure 38 Model 7 - View on the station square*

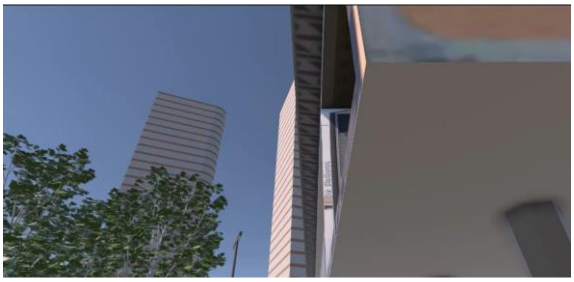
*Figure 39 Model 7 - View on building height*

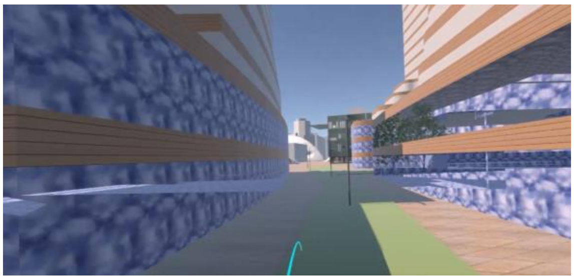
*Figure 40 Model 7 - View towards the city centre*

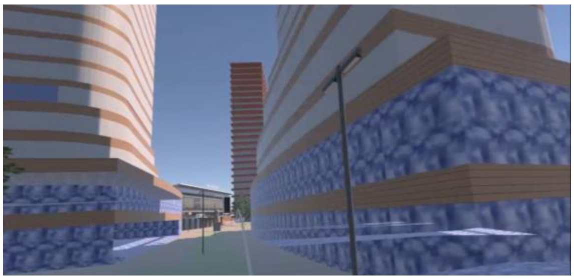
*Figure 41 Model 7 - View towards the station*


*Figure 42 Model 8 - View on the station square*


*Figure 43 Model 8 - View on building height*

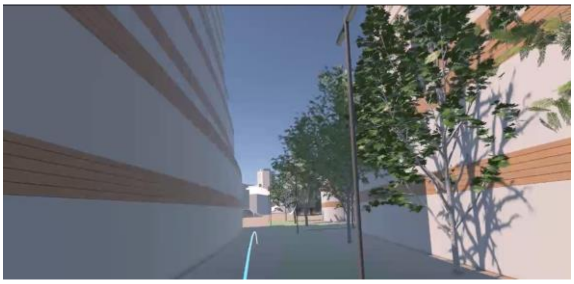
*Figure 44 Model 8 - View towards the city centre*


*Figure 45 Model 8 - View towards the station*

### 3.1.3 The Questionnaire

To capture the participants' experience, they will fill out a questionnaire during the experiment. The questionnaire will consist of two parts and will be presented in an online format.

The first part will focus on the personal characteristics. As described in Figure 5, this part will ask about the participants' gender, age, living environment, frequency of visiting high-rise environments, personality, and mood. Before the participant is presented with the VR models, they will fill out the first part of the questionnaire. This part consists of an explanation of the experiment, an informed consent form and some questions to identify the personal characteristics. The questions and corresponding answers are summarised in Table 6, Table 7, and Table 8. To determine the mood, the current feelings of safety, comfort, annoyance, and happiness are questioned. These are the same questions as are used to determine the user-experience, as the mood at a certain moment defined by the emotions they are experiencing at a certain moment, just like the user-experience.

*Table 6 Overview of Multiple-Choice questions regarding personal characteristics*

| *Question* | *Answer A* | *Answer B* | *Answer C* | *Answer D* | *Answer E* |
|---|---|---|---|---|---|
| *What is your gender?* | Female | Male | | | |
| *What is your age?* | 18-21 | 22-25 | 26+ | | |
| *What would describe the urbanisation level of your living environment best?* | Rural | Suburban | Urban | | |
| *How frequent do you visit high-rise environments?* | Never | Rarely | Sometimes | Often | Usually, |

*Table 7 Questions to determine personality on a 5-point Likert scale*

| *To what extent do the following statements describe your personality?* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| *I am arousal seeking* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| *I am extrovert* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| *I have tendency towards negative feelings* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |

*Table 8 Questions to determine mood using a 5-point Likert scale*

| *Question* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| *I feel safe* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| *I feel comfortable* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| *I feel annoyed* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| *I feel happy* | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |

Once the questions regarding personal characteristics are answered, the VR experiment will start. It is important for the user to feel confident before the beginning of the experiment and being introduced to the different VR models. Therefore, it is possible to do a test round in a model with solely a walking plane, as other details in the model might influence the outcome of the experiment. They will shortly visit this practice model, and once familiar with the equipment, the next part of the experiment can start. Each participant will visit a maximum of three different models. Visiting more models might lead to fatigue and/or other symptoms of cybersickness. Which three models the participant will visit will be randomised, as well as the order of them, see Table 9. In the end each model will be visited an equal number of times and the order in which the model is presented is balanced as well, as specified in Table 10.

*Table 9 Models visited per participant*

| PARTICIPANT | FIRST | SECOND | THIRD | PARTICIPANT | FIRST | SECOND | THIRD |
|---|---|---|---|---|---|---|---|
| **1** | 1 | 8 | 7 | 17 | 7 | 6 | 2 |
| **2** | 2 | 3 | 5 | 18 | 2 | 4 | 8 |
| **3** | 6 | 4 | 3 | 19 | 2 | 3 | 4 |
| **4** | 4 | 8 | 1 | 20 | 1 | 5 | 7 |
| **5** | 7 | 2 | 5 | 21 | 4 | 7 | 6 |
| **6** | 6 | 2 | 3 | 22 | 8 | 5 | 3 |
| **7** | 6 | 5 | 4 | 23 | 1 | 2 | 7 |
| **8** | 7 | 8 | 1 | 24 | 5 | 6 | 7 |
| **9** | 8 | 7 | 3 | 25 | 3 | 1 | 4 |
| **10** | 6 | 5 | 1 | 26 | 5 | 3 | 2 |
| **11** | 4 | 1 | 2 | 27 | 7 | 3 | 8 |
| **12** | 3 | 7 | 6 | 28 | 8 | 4 | 1 |
| **13** | 4 | 8 | 5 | 29 | 1 | 6 | 8 |
| **14** | 8 | 2 | 4 | 30 | 5 | 6 | 2 |
| **15** | 5 | 7 | 6 | 31 | 2 | 1 | 6 |
| **16** | 3 | 1 | 5 | 32 | 3 | 4 | 8 |

*Table 10 Frequency of Model Visits*

| ***MODEL NUMBER*** | FIRST VISITED | SECOND VISITED | THIRD VISITED | TOTAL |
|---|---|---|---|---|
| ***1*** | 4 | 4 | 4 | 12 |
| ***2*** | 4 | 4 | 4 | 12 |
| ***3*** | 4 | 4 | 4 | 12 |
| ***4*** | 4 | 4 | 4 | 12 |
| ***5*** | 4 | 4 | 4 | 12 |
| ***6*** | 4 | 4 | 4 | 12 |
| ***7*** | 4 | 4 | 4 | 12 |
| ***8*** | 4 | 4 | 4 | 12 |

After each visit to a VR model, the participant will be presented with the second part of the questionnaire. During the literature review it was determined that user-experience could be captured by questioning the four basic emotions: safety, comfort, annoyance, and happiness. Therefore, the participants will be presented the following questions: How safe/comfortable/ annoyed/happy do you feel right now? The answer is captured using a 5-point Likert scale, as described in Table 11. The questionnaire questions are asked to be able to analyse the data gathered, as the group of participants is limited. The participants would visit the VR model, then take off the headset and answer the questions on user-experience for that model. Questions asked as open questions in the questionnaire are: “Could you explain why you felt (un)happy/(un)safe/ (un)comfortable/annoyed (or pleased)” and “Would you like to visit this area again? Why (not)?”. These questions help getting more insight into their experiences and provide context to the gathered data.

*Table 11 Questions to determine user-experience using a 5-point Likert scale*

| *Question* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| I feel safe | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| I feel comfortable | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| I feel annoyed | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
| I feel happy | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |

Next to the data of the cylinder game object mimicking the participant’s gaze, observations will be made of the participant’s behaviour in the model. Notes will be made about where the participant spends relatively more time, what order they look at the different attributes and if they return to particular ones. Based on these notes, a short interview will be held with the participant after they have filled out the questionnaire questions regarding the model they have just visited. Questions that could be asked are: “Was there something in the model that caught your attention?”, “During the walkthrough you spent some time at [insert location] / looking at [insert attribute], could you elaborate on why?” and “During the walkthrough you decided to revisit [insert location] or [insert attribute], could you explain why?”. More deepening questions could be asked based on the answers given. The answers to these questions could help bridging the data from the questionnaire and the data gathered by the scripts.

After visiting three different models and answering the model specific questions, some additional questions will be asked on their experience in VR and if they experienced any form of cybersickness, if they formed an opinion about the development plans or if their previous opinion has changed, how they would improve the area to increase user-experience and finally if the separate attributes contributed to their experience in the area. The open questions at the end will provide more insight into their experience using VR, as cybersickness or their attitude towards using VR might influence/bias their answers; their general opinion about the project, as their opinion might bias their experience when visiting the model; their personal preferences and priorities by asking for suggestions to improve; and the importance of the separate attributes in their experience.

The full questionnaire is included in Appendix B.

### 3.2 Ethics and Data Management

The experiments require human participants and gather personally identifiable information. Therefore, it is important to conduct the experiments ethically and safely, and work with and store the data in a safe manner. Next to safe data management, it is important to execute the research ethical and with integrity. There are five principles on which the code of conduct of integrity in research is based: Honesty, Scrupulousness, Transparency, Independence, and Responsibility (Netherlands Code of Conduct for Research Integrity, 2018).

Before a participant can start the experiment, informed consent is required. They should be given sufficient written information to be able to decide whether or not they want to participate in the study. Therefore, each participant will be presented with the informed consent form as added in Appendix C. Informed Consent Form

Each participant will be assigned a participant number as identifier for the data gathered during the experiment. The personal data gathered will only be used for the purpose of analysing a possible relation between the personal characteristics and user-experience, limiting the collection of personal data to the attributes described in Appendix B. As the personal data is categorised and each participant will be identified by a participation number, the personal data is anonymised. In the master thesis report only summarised data will be presented, protecting each participant's output.

The reference of the approval letter of the Ethical Review Board of the TU/e is: ERB2023BE8.

### 3.3 Data Collection and Analysis

The data collection took place between February 15th and March 5th, 2024. Participants were recruited from the university, due to the time limitations and the location of the experiments, which is the EAISI Digital Twin Lab on the campus of the Eindhoven University of Technology. The aim was to recruit at least 30 participants.

The participant will visit environment in immersive VR, they will not be made aware of the attributes that vary. Hence they will perceive the environment as a whole, rather than a collection of attributes. A cylinder-shaped game object (visualised by the red lines in Figure 11) is placed relatively to the headset, to mimic the line of sight. If the game object interacts with one of the colliders (visualised by the green lines around the attributes in Figure 11) of the attributes in the environment, this will be logged in a csv file, so the interactions can be analysed. The position and rotation of the headset will be logged every 0.5 seconds as well, to get insight into the places they tend to spend most of their time and where they look around. These observations can be captured in heat maps for the positions, which visualise where the participants spent most time, and graphs with position points from which the lines of sight are depicted as spikes. The observations are then processed by the individual and influenced by their personal characteristics. This then translates to the user-experience, and when combined with the heat maps, the headset rotation graphs and the interactions, it can be analysed if there are relations between their behaviour and user-experience.

The order of the experiment is: opening with a short verbal introduction by the researcher, then the participants read and check the informed consent form, next they will answer the questions on personal characteristics. When ready they will read the short scene description of the experiment, which will be explained verbally by the researcher as well. During the explanation, a map of the VR model is shown, indicating the walkable areas. Afterwards the researcher and participant walk over to the headset to adapt it to fit the participant and explain the controls. If the participant indicated to prefer to try out the headset and controller commands in a blank model first, the researcher would load a blank model, where the participant could try out the headset and controls till they indicate they feel confident to start the model. Then the researcher would start the first VR model, and the participant is free to walk around, until they indicate to have gotten a good feeling of the area. In the meantime, the researcher takes notes of what they are looking at and their walking path. Then the researcher would stop the simulation, the participant would take off the headset and return to the questionnaire to answer the 5-point Likert scale questions on user-experience, as well as the open questions to elaborate on it. Based on the notes taken whilst the participant was in the VR environment, the researcher asks some elaborating questions on their experience. Then the participant will visit the second model and third model, following the same procedure. Finally, after answering the final interview questions of the third visited model, the participant is presented with additional questions on their VR experience in general, whether or not they experienced symptoms of cybersickness and some open questions on the influence of the separate attributes on user-experience. When all questions are finished, the participant submits the questionnaire and the researcher thanks the participant for their contribution.

The participants were presented with the scenario that they are going to pick up a friend from the train station, however, their friend's train is delayed, so they decide to kill the time walking around the area. They will walk from the train station building to the small square in between the newly developed buildings on the left side, as indicated before in Figure 8. The three different models they visited were randomly selected. The complete process of the experiments is visualised in Figure 46.

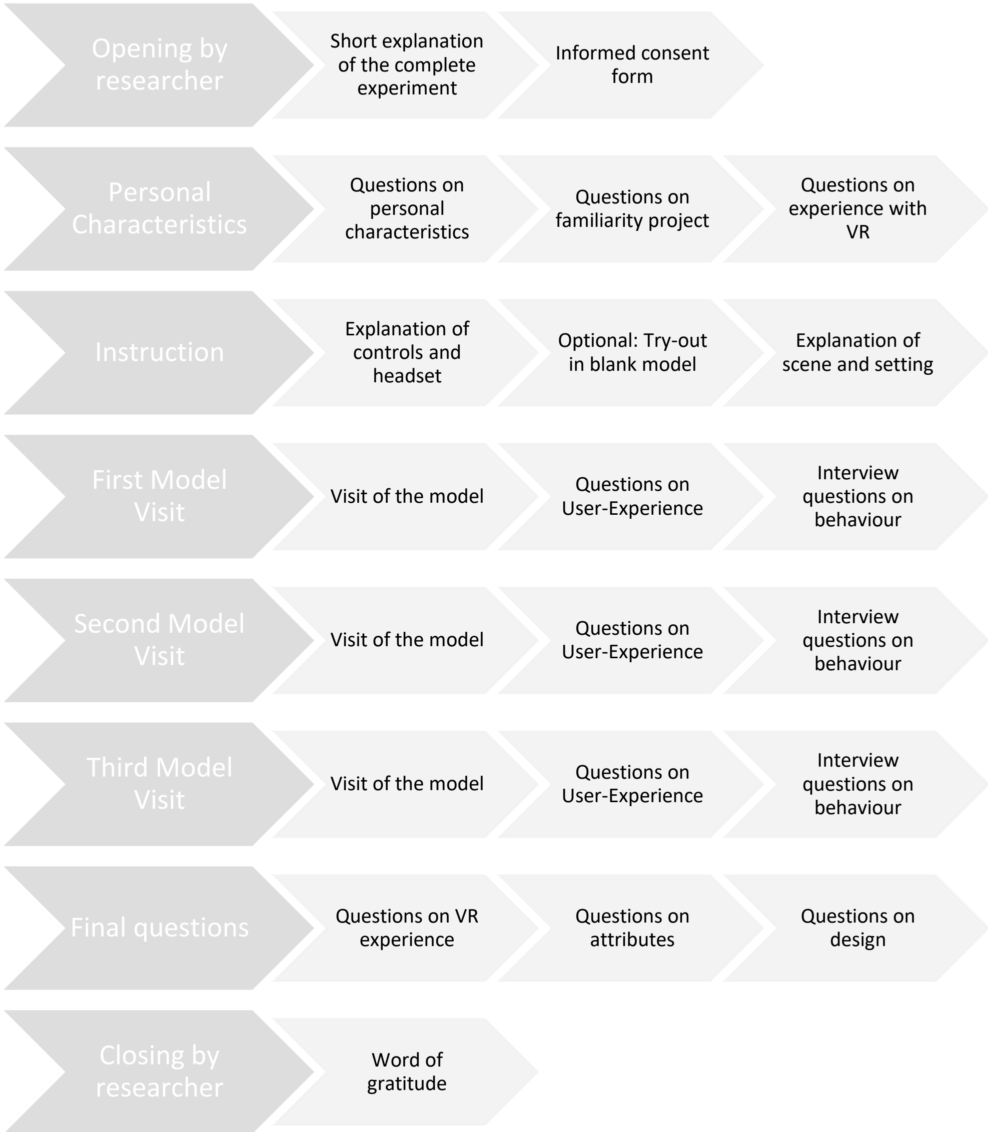


*Figure 46 Process of the Experiment*

The questionnaire was presented in an online format using LimeSurvey. All questions require dan answer before the form could be submitted, and the answers were automatically collected in a table, which could be used for the statistical analysis. From literature it followed that the data gathered to describe the user-experience can be treated as a single dependent variable. To check this, the reliability will be evaluated using Cronbach's alpha (Zhao, van den Berg, Ossokina, & Arentze, 2022). The same approach will be used to determine whether the mood of the participant before the experiments can be treated as a single independent variable. In order to check the Cronbach's alpha, the variable *Annoyance* needs to be recoded, as it is depicting a negative experience, whereas the other user-experience variables are depicting a positive experience. If the Cronbach's alpha is higher than 0.7, the four variables, including the recoded variable of *Annoyance* instead of the initial one, are combined into one variable for user-experience, using the average value of the four. Then a linear regression will be run with the environmental characteristics as independent variables and the newly computed user-experience variable as dependent variable. A linear regression will be run for the first, second and third visited models separately, as well as combined. Next to that a linear regression will be run with the user-experience variable being computed as the sum of the four variables, instead of the average. And finally, a fixed-effects panel regression will be executed, as the personal characteristics of the participant stay constant throughout the three models they visited. The significance of the result will then provide insight into whether there is a relation between the environmental characteristics and user-experience.

The answers to the open questions and interview questions will be open-coded, using a descriptive coding method (Saldaña, 2009). This process will take place in several iterations to go from the answers given to identifying several themes/categories. These answers will help explain the scores given to the closed questions and allow participants to describe their experiences in their own word. So, the answers to the open questions will be reduced to general categories, the number of times this theme was mentioned per model will be captured, as well as the direction of the relation to user-experience, if indicated. This will result in tables with the theme, the count of mentions and the indicated effect on user-experience. These themes could then be compared per model.

For every VR model visit, the position tracking data will be saved in a csv file as separate points. These can be processed into heat maps using MATLAB. These will visually represent the participants walking path and pauses. From these heatmaps could then be deducted the positions most time is spent per model. The maps per model could then be compared to one another and to the answers given to the open questions. Their gaze behaviour will be approximated by data points of the interaction between the cylinder object and variable collider, as well as the rotation data of the headset. This will result in a csv file indicating the time of interaction and the variable interacted with, and a csv file with the rotations. The interaction data can be summarised in tables, grasping the gaze points and scan paths. The rotation points can be visualised in 3D graphs, with the rotation being visualised as lines. Then the data can be compared per model.

### 3.4 Conclusion

The aim of this chapter was to design an experiment using Immersive Virtual Reality and eye-tracking observations. Next to that, it elaborated on the ethical aspect, data management and data collection. Finally, it laid the foundation for the data analysis in the results section.

Based on the literature review, the variables for personal and environmental characteristics were identified. At first, eight models of KnoopXL Eindhoven are created in SketchUp, in which *building height, variation in building height, active or blank façades, grass coverage, number of trees, clustering of trees,* and *presence of water* are varied between two attribute levels, based on orthogonal experimental design. Then these models were imported in a Unity environment and VR elements were added, such as the controllers for the headset and a transportation area where the participants could walk. Next to that, a cylinder game object was connected to the headset to mimic the participant's gaze. To the cylinder and the attributes collider objects were added, which registered when an interaction between two collider objects happed. C# scripts were added to the hierarchy to log the participants ID number and model they were visiting, to log their position and the rotation of the headset every 0.5 seconds and to log the interaction between the cylinder and the collider objects.

A questionnaire was created using LimeSurvey, which exists of three parts. The first part is general introduction to the experiment, the informed consent form, and questions on personal characteristics such as *gender, age, mood, living environment* and *familiarity with the project.* Then, the middle part was split into the three models visited, with per model a 5-point Likert scale on *Safety, Comfort, Annoyance* and *Happiness.* Additionally, there were open questions asking the participants to elaborate on what made them feel that way. Additionally, a short interview will be held after each visit to the model and answering the corresponding questions in the questionnaire, asking the participants to elaborate on their experiences and behaviours.

This will result in several types of data collected. The open questions and interview questions will be coded using an open coding method, with several iterations. The data points of position will be visualised in heat maps per model using MATLAB. Additionally, the data points of rotation will be visualised in 3D maps per model using MATLAB as well. The data points on gaze and scan path will be gathered in Excel tables and the interactions will be counted. Lastly the Cronbach's alpha will be checked whether the variables for mood and user-experience could be computed into one variable instead of four. If so, the new variables will be computed. Several regression models with the environmental characteristics as independent variables and the user-experience as dependent variable will be run to determine whether there is a relation between environmental characteristics and user-experience. A linear regression will be run for the first, second and third model separately, as well as for all models combined. Next to that, a fixed effect panel regression will be run with all the cases.

# 4. Results

*This chapter will discuss the results of the experiments to evaluate the gathered datasets against the findings in literature and the statistical significance. At first the sample characteristics will be discussed. Then the position analysis will take place and an analysis of the interactions between the eye cylinder and environmental variables is undertaken. The process of the coding of the answers to the open questions and interview questions will be described and the answers discussed. Finally, this chapter will answer the main question by running statistical analyses on the influence of environmental characteristics on the user-experience.*

## 4.1 Sample

In a period of three weeks, from February 15th to March 5th, 2024, a total of 32 individuals have participated in the VR experiment. It took approximately one hour to complete the experiment and questionnaire. Of the 32 participants, 13 participants identified as male and 19 participants identified as female. All participants participated in every part of the experiment, thus there were no missing values.

As the participants were recruited on campus, all participants were students. The variable age has been split in three categories, 9 respondents were between 18 and 21 years old, 15 respondents were between the 22 and 25 years old, thus the largest category, and 8 participants were 26 years old or older. As visualised in Figure 47.

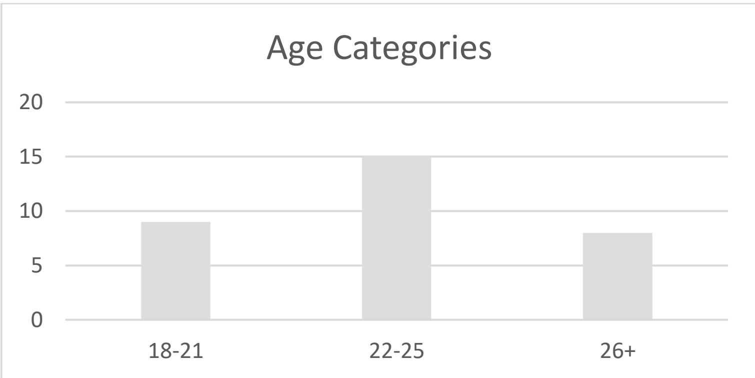


*Figure 47 Age Categories*

Next to that, data on the current living environment of the participants was collected and analysed. As the participants were recruited on campus, most of them live in an urban environment. A total of 6 participants indicated to live in a suburban environment and 4 indicated to live in a rural environment. The number per category is visualised in Figure 48.

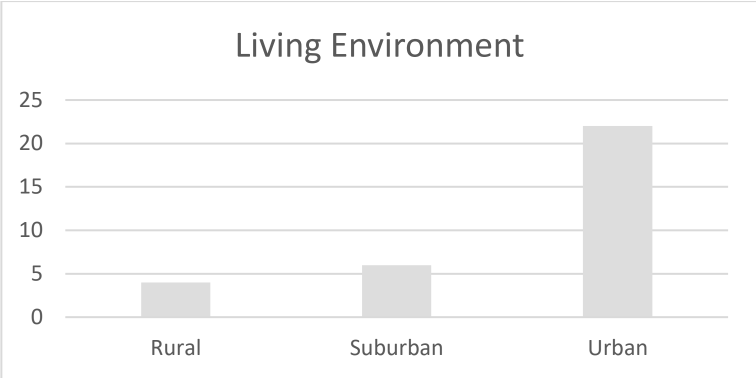

*Figure 48 Living Environment of Participants per Category*

Furthermore, it was asked how frequently the participants would visit high-rise environments. This variable was split into 5 categories, ranging from rarely to once a week or more often. Most of the participants are frequent visitors of high-rise environments, as visualised in Figure 49.

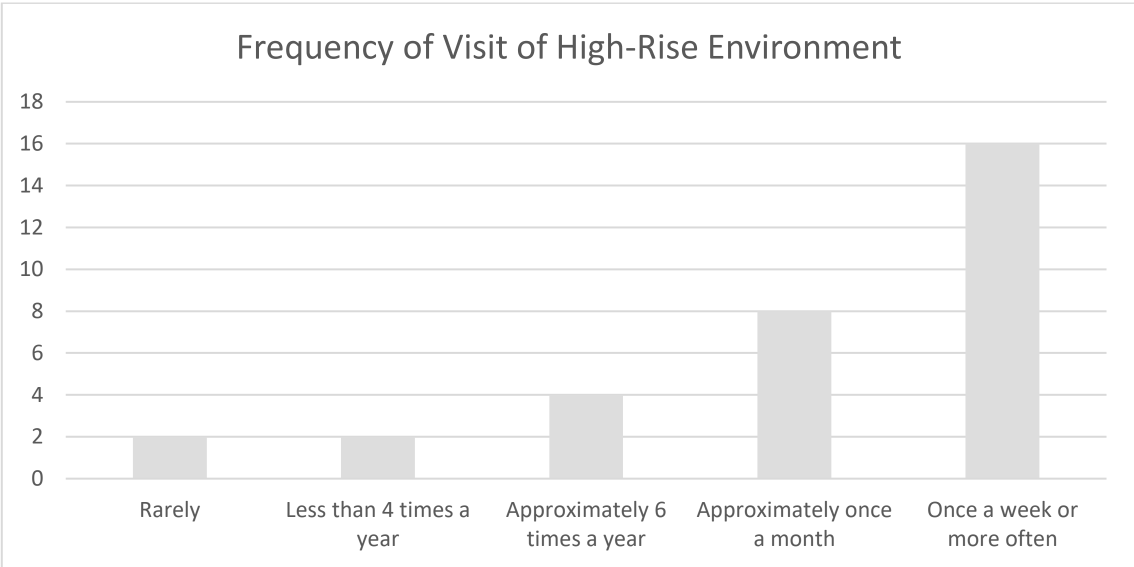

*Figure 49 Frequency of Visit of High-Rise Environment Categories*

Due to the high number of participants having a high frequency of visit, it has been decided to combine the categories “rarely” and “less than 4 times a year” into one category named “rarely”, and the categories "approximately 6 times a year” and “approximately once a month” into one category “sometimes” for the rest of the analysis. Which resulted in the division as shown in Figure 50.

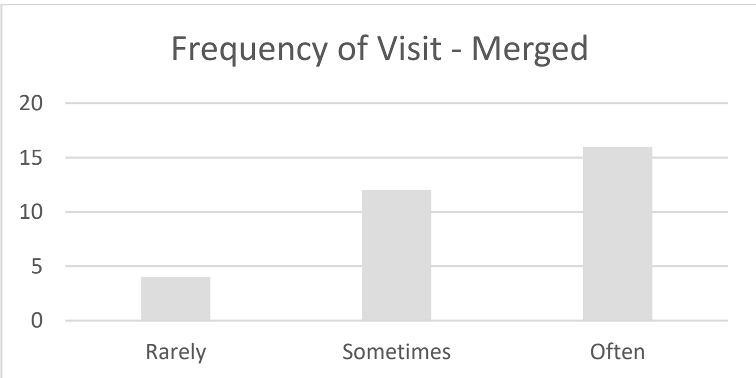

*Figure 50 Frequency of Visit with Merged Categories*

Participants were asked to assess their personality using a 5-point Likert-scale to indicate their agreement with the following statements: I am arousal seeking, I am extrovert, and I have a tendency towards negative feelings. The descriptive statistics are summarised in Table 12, and the count per variable is visualised in Figure 51. The means of “I am arousal seeking” and “I am extrovert” both equal 3.56, with a standard deviation of 0.801 and 1.105, respectively. This means that the sample showed a moderate inclination towards arousal-seeking behaviours and extroversion. The category “Tendency towards negative feelings”, on the other hand, has a mean of 2.75 with a standard deviation of 1.136. Thus, the sample tends to experience fewer negative emotions.

*Table 12 Descriptive Statistics of Personality Variables*

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Arousal Seeking | 32 | 2 | 5 | 3,56 | ,801 |
| Extrovert | 32 | 2 | 5 | 3,56 | 1,105 |
| Negative Feelings | 32 | 1 | 5 | 2,75 | 1,136 |

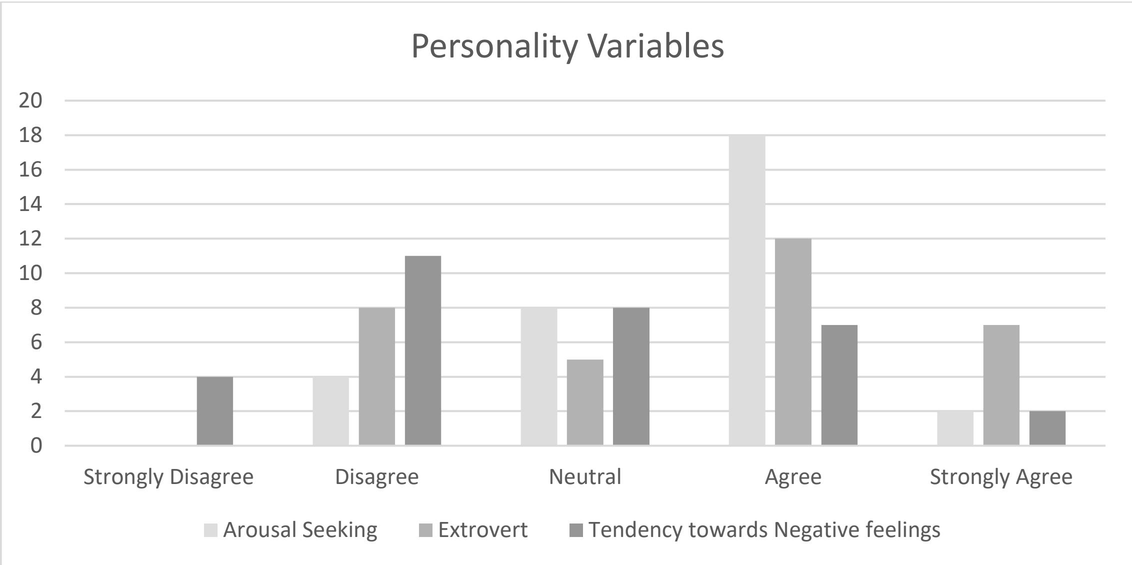


*Figure 51 Personality Variables*

The participant’s mood at the start, assessed as a baseline measurement, was recorded before participants visited the virtual environments. To determine the mood, the same four variables are used as for the user-experience, namely safety, comfort, annoyance, and happiness. The Likert-scale ratings on the four variables are visualised in Figure 52.

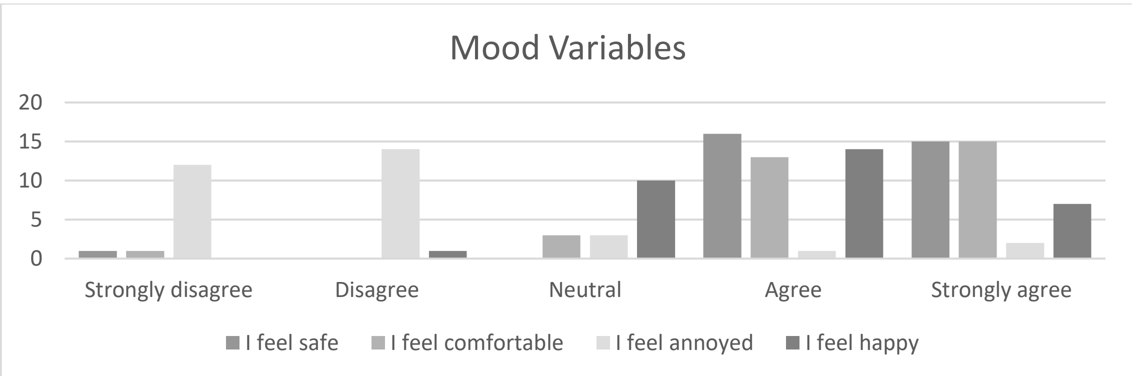


*Figure 52 Mood Variables*

The variables safety, comfort and happiness indicate that a high score means a more positive mood, whereas the variable annoyance indicates the higher the score, the more negative the mood. Therefore, the scores assigned to annoyance were inverted and a new variable "Pleasure" was created, as the opposite of annoying is pleasant. The Cronbach's alpha was calculated, for the variables: *safety, comfort, pleasure*, and *happiness*, to determine whether these variables could be combined to one variable to describe the mood. The Cronbach's alpha equals 0.826 (Table 9), which is larger than 0.7, thus a new variable called Mood was created taking the average value of the four initial variables of the participant. Looking at the sample, the mean of the variable mood equals 4.13, as calculated in Table 13, meaning that the general mood was positive.

*Table 13 Calculation Cronbach's Alpha*

| **Cronbach's Alpha** | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| ,826 | ,841 | 4 |

*Table 14 Descriptive statistics Mood*

| | **N** | **Minimum** | **Maximum** | **Mean** | **Std. Deviation** |
|---|---|---|---|---|---|
| Mood | 32 | 1,25 | 5,00 | 4,13 | ,732 |

Most of the participants indicated to have used a head-mounted display before, namely 22 participants. Out of these participants 3 even indicated to use one regularly. 9 Participants indicated to not have used a head-mounted display before.

When asked whether they were familiar with the redevelopment plan, 18 participants indicated that they did not hear about the redevelopment before, 14 of the 32 participants responded positively. Most of them only heard from the redevelopment plan, but are not yet familiar with the details. When asking their opinion, most were interested in how the redevelopment would fit the city in terms of size and urban design. There were some concerns regarding the commercial and public spaces, whether they would be filled, and if the tall buildings would impact the sense of scale.

At the end of the survey the participants were asked to indicate whether they experienced some symptoms of cybersickness. A total of 12 participants indicated that they experienced cybersickness symptoms to some extent. All participants were able to finish the experiments completely. Most experienced cybersickness symptoms were disorientation and nausea, the total number of experienced symptoms is visualised in Figure 53.

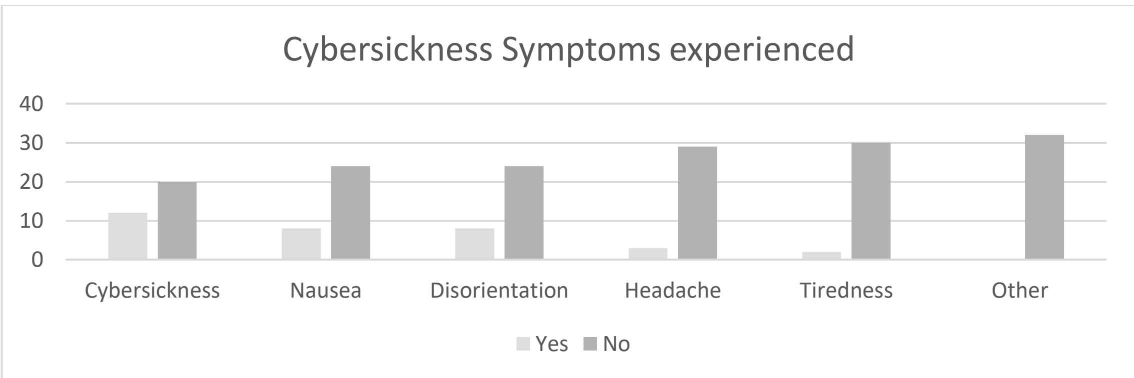


*Figure 53 Cybersickness Symptoms Experienced*

### 4.2 Thematic Analysis

The open and interview questions were analysed using an open, descriptive coding method. A total of three iterations rounds were conducted. At first the most important quotes of the participants were collected, then the themes of these quotes were analysed and assigned. Finally, these themes were described according to the literature review conducted in Chapter 2.

#### 4.2.1 Interview Questions

After the iterations on the thematic analysis of the interview questions were finished, a table was created summarising the number of times the characteristics were mentioned per model, and whether they had a positive or negative influence on the user-experience. The total amount of times a characteristic was mentioned in an answer to the interview questions is summarised, in the second column "Count", in Table 15. The "+" and "-" signs in the column "Effect" indicate whether there is a positive or negative relation mentioned between the characteristic and the user-experience.

*Table 15 Characteristics in Interview Answers*

| ***Characteristics*** | ***Count*** | ***Effect*** |
|---|---|---|
| Number of trees | 40 | -/+/- |
| Overall building height | 24 | - |
| Sense of scale | 21 | + |
| Amount of grass | 20 | -/+/- |
| Presence of water | 19 | + |
| Presence of daylight | 12 | + |
| Active façade | 10 | + |
| Level of architectural detailing | 8 | + |
| Sense of place | 7 | + |
| View of the sky | 5 | + |
| Clustering of trees | 5 | -/+/+ |
| Variation of building height | 4 | + |
| Presence of streetlighting | 3 | + |

From the table it can be concluded that the overall building height has a negative relation to the user-experience, meaning that the taller a building is, the more negatively the user-experience is influenced. The other characteristics all indicate a positive relation to the user-experience, meaning that with an increase of sense of place and sense of scale, the user-experience becomes more positive. The same applies to the variation in building height, view of the sky, presence of daylight, presence of streetlighting and presence of water. The type of façade influenced the user-experience as well, here it is important to note that an active façade had a positive influence on the user-experience, whereas the blank façades had a more negative influence on the user-experience. The level of architectural detailing was not varied in the models; however, some people found the edges of the buildings to be sharper/rounder or noticed the shape of the buildings in general. Most heard comments on this characteristic that the rounder edges provided more overview and that the shape and design of the buildings, not regarding the building height, were inviting.

For the amount of grass, the number of trees and the clustering of trees something interesting was going on. In general, people preferred the presence of grass, however, the placement raised some concerns. The station square is a heavily frequented area by people traveling from and to the city. The grass created some more calmness and indicated places to rest and hang out, which positively contributed to the user-experience. The grass on the route from the station to the central square created more narrow paths and pushed the participants into a certain direction, which is not desirable. Therefore, it applies that in general, the addition of some grass has a positive effect on the user-experience, however, too much grass or grass interfering with the main walking paths has a slight negative effect.

Regarding the number of trees and the clustering, a similar principle applies. When the trees were spread, few trees were preferred over many trees. In the models with many spread trees, participants experienced the trees to be everywhere, it was an overwhelming amount. In the models with few spread trees, participants found the trees to balance out the urban vibe of the area, provide some shelter from the building height and indicate the route in an intuitive manner. If the few trees were clustering, on the other hand, it was perceived as there hardly being any trees, which was not desirable and impacted the user-experience negatively. Some terms describing the situation were “sterile”, “hard”, and “uninviting”. When answering the interview questions regarding the models with many trees Clustering, the participants indicated that the tree clusters indicated some places to rest and to stay, contrasting the traffic areas, which influenced their experience in a positive manner. In general, the presence of greenery acts like a green buffer, contrasting the urban vibe. However, the placement and design of the green elements play an important role. A total overview of the mentions of characteristics per model is summarised and visualised in Figure 54.

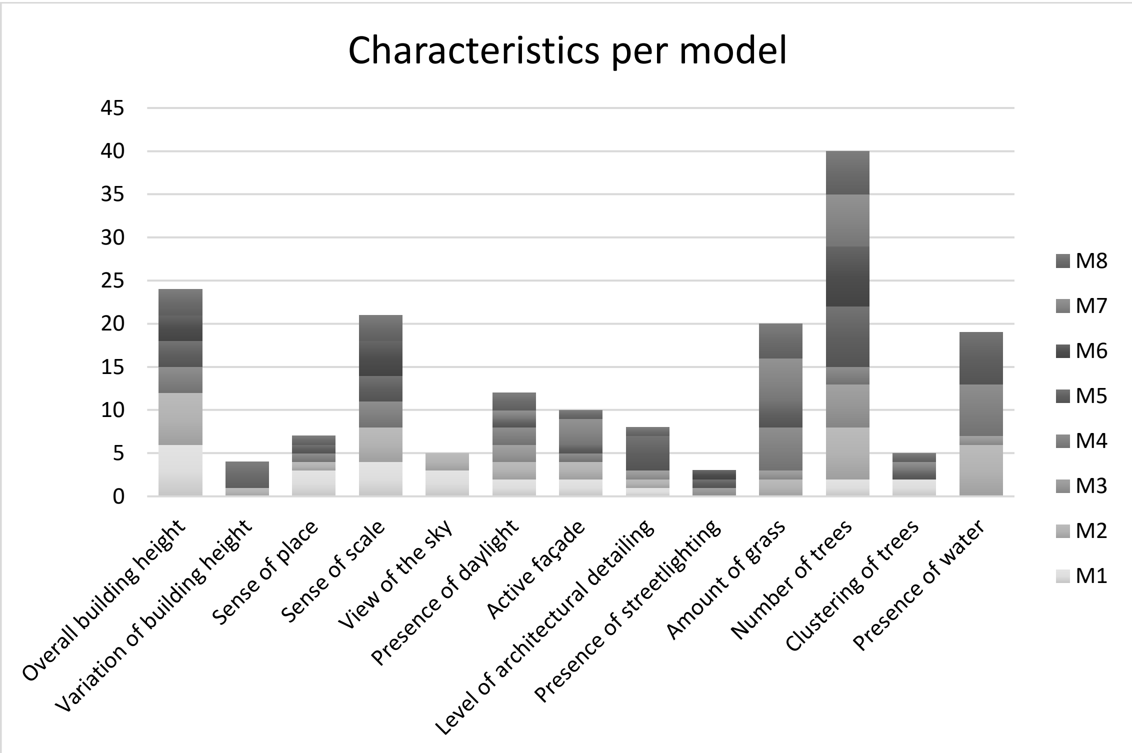


*Figure 54 An overview of the number of times a characteristic was mentioned per model.*

### 4.2.2 Open Questions

The method used to analyse the answer to the interview questions, was also applied to the answers to the open questions. The open questions exist of two parts. The first part includes the questions regarding safety, comfort, annoyance, happiness and whether the participants would like to visit the area again. The second part of the open questions were asked at the end of the questionnaire and questioned the participants on their experience in VR, their opinion about the redevelopment and whether the separate characteristics influenced their experienced.

#### *4.2.2.1 Environmental Characteristics Mentioned per Model*

When looking at the number of times the various characteristics were mentioned in the open question answers, several differences can be noticed. First, the *Annoyance* table. Safe, comfortable, and happy are all positive, whereas annoyance has a more negative connotation. As a result, the effect of the different characteristics on the user-experience variable are opposite of the effects indicated in the other three tables. Except for the effect of presence of grass. The answers indicated a positive effect of the presence of grass on the level of annoyance they experienced. The main reason given is that the grass in the current design interfered with the routing. Participants were either forced to walk around the grass, which caused them to experience a rather narrow walking path and being pushed out of the area. Some participants would walk over the grass, but they would be annoyed due to the implications, such as mud and uneven ground.

*Table 16 Characteristics in answers to open questions per user-experience variable*

| | **Safe** | | **Comfortable** | | **Annoyance** | | **Happy** | |
|---|---|---|---|---|---|---|---|---|
| **Characteristics** | Count | Effect | Count | Effect | Count | Effect | Count | Effect |
| *Number of trees* | 19 | -/+/- | 27 | -/+/- | 30 | -/+/- | 24 | -/+/- |
| *Presence of daylight* | 13 | + | 10 | + | 2 | - | 3 | + |
| *Overall building height* | 9 | - | 6 | - | 4 | + | 1 | - |
| *Sense of place* | 9 | + | 4 | + | 1 | - | 2 | + |
| *Active façade* | 8 | + | 7 | + | 5 | - | 2 | + |
| *Amount of grass* | 6 | -/+/- | 9 | -/+/- | 12 | + | 7 | -/+/- |
| *Sense of scale* | 5 | + | 17 | + | 4 | - | 0 | |
| *Presence of water* | 4 | + | 4 | + | 9 | - | 17 | + |
| *Presence of streetlighting* | 4 | + | 1 | + | 0 | | 0 | |
| *View of the sky* | 3 | + | 2 | + | 0 | | 1 | + |
| *Clustering of trees* | 1 | -/+/+ | 0 | | 3 | - | 0 | |

When looking at the total counts over the four different user-experience categories, as visualised in Figure 55, the number of trees really stand out as most mentioned, is followed by the presence of water and the amount of grass. Similar to the answers to the interview questions, the presence of trees was often mentioned, but the effect on user-experience could not necessarily be described as linear. Also in the open questions per user-experience variable it came forward that few trees spread, or many trees clustering had a more positive effect on the user-experience, whereas many trees spread often increased the annoyance and decreased the feeling of safety and comfort, and few trees clustering resulted in a lack of trees, which mainly decreased the feeling of comfort.

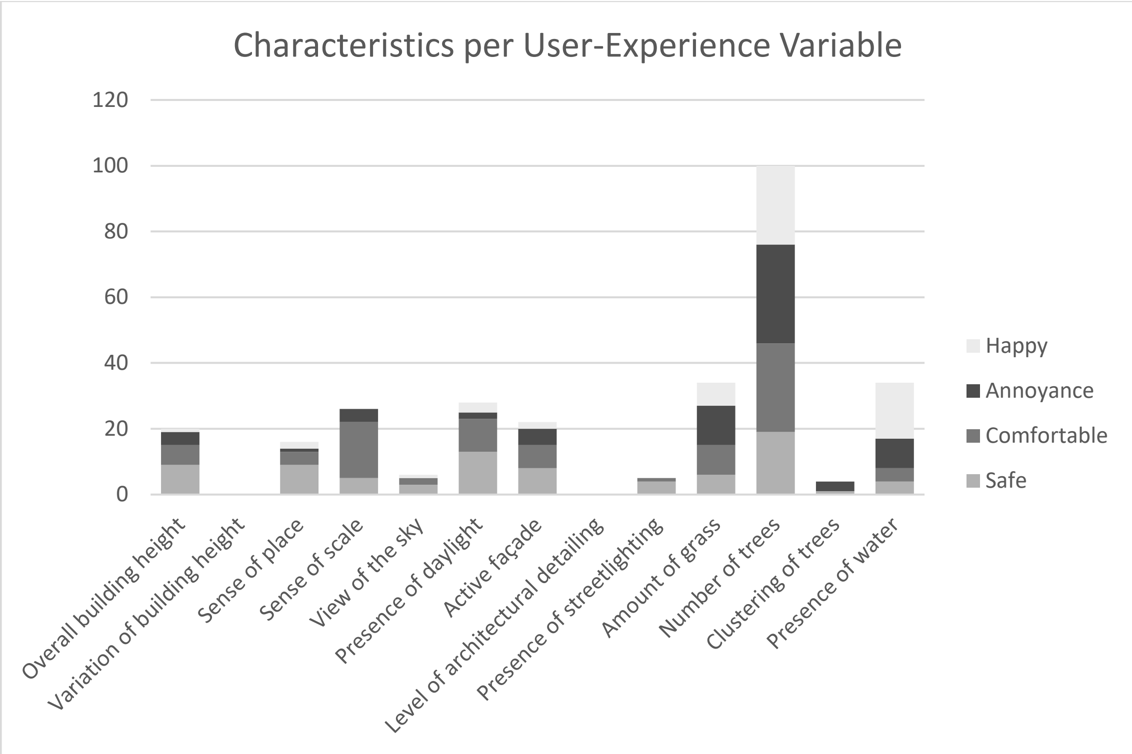


*Figure 55 An overview of the number of times a characteristic was mentioned per user-experience variable*

The presence of water was incorporated into the models as water fountains. These had mainly a positive effect on the feeling of happiness, as participants indicated their presence as fun and dynamic.

The complete thematic analysis tables of both the interview question and the open questions can be found in Appendix D.

#### *4.2.2.2 Experience of Attributes*

At the end of the questionnaire, the different attributes were listed and the participants were asked to elaborate on whether or not the attributes influenced their user-experience, and if they prefer a certain attribute level. Similarly to the open questions analysed before, the answers were analysed using an open, descriptive coding method. The answers are gathered in tables summarising the notes of the participants per attribute.

In the analysis of the answers to the interview and open questions, the building height was often mentioned to decrease the feelings of safety and comfort when visiting models with skyscrapers. This coincides with the explanation given at the end of the survey, where 15 participants indicated to prefer a lower building height, as can be seen in Table 17. Some of the participants indicated that tall building heights were experienced as contrasting with the surroundings, overwhelming and/or claustrophobic, which negatively affected their experience. Three participants indicated that the tall buildings affected their experience in a positive manner, as they found the building height impressive. Interestingly, four participants indicated that the open façade distracted them from the building height, which positively influenced their experience. Which suggests that the use and design of the plinth is more important to them than the actual building heights.

*Table 17 Answers to environmental attributes influencing user-experience: Height*

| Summary | Count | Effect |
|---|---|---|
| Preference for lower buildings | 15 | + |
| Sense of scale missing | 7 | + |
| Overwhelming | 5 | - |
| View of the sky preferred | 5 | + |
| Claustrophobic | 5 | - |
| Concerned about shadows | 5 | - |
| Sense of place missing | 4 | + |
| Public plinth distracts from building height | 4 | + |
| Impressive | 3 | + |
| Contrasting | 2 | - |

Next to the building height, the literature review suggested that the variation in building height could influence the user-experience. Table 18 suggests that almost a third of the participants indicated that they do not have a preference regarding the building height variation. Twelve participants mentioned that they found variations in building height to be more dynamic and make the environment more interesting, this positively influenced their experience. Furthermore, some participants pointed out that the height variations were opening up their view to allow views of the sky and/or city, positively contributing to their sense of scale or sense of place respectively, and in general made the environment less overwhelming.

*Table 18 Answers to environmental attributes influencing user-experience: Height Variation*

| Summary | Count | Effect |
|---|---|---|
| Variation is more dynamic/interesting | 12 | + |
| No preference | 11 | |
| Variation is less overwhelming | 4 | + |
| Layering in the plinth opens up the area | 2 | + |
| Variation allows view of the sky | 2 | + |
| Variation allows view of the city | 1 | + |

Following Table 19, a majority of the participants argued that the active façades opened up the area, making it more welcoming, thus enhancing the experience. Four participants pointed out that, contrary to blank façades, active façades had some reflections of the sky in their glass, which added daylight to the area.

*Table 19 Answers to environmental attributes influencing user-experience: Façade*

| Summary | Count | Effect |
|---|---|---|
| Active façades open up the area | 25 | + |
| Prefer reflections of the sky | 5 | + |
| No preference | 4 | |
| Open façade adds more contrast | 1 | + |

Two experiences stood out regarding the addition of grass to the environments, as summarised in Table 20. On the one hand the addition of greenery added positively to the user-experience, as participants found it a positive contrast to the urban environment. It made them more comfortable and added to the liveliness and playfulness. On the other hand, by the design of the grass in the model, the walkability of the area was decreased, as people tend to walk around grass, rather than walking on it. Therefore, the layout and placement of grass fields in urban areas are important to the experience as well.

*Table 20 Answers to environmental attributes influencing user-experience: Grass*

| Summary | Count | Effect |
|---|---|---|
| Comfortable | 16 | + |
| Contrasts the urban environment | 13 | + |
| Limits walkability | 9 | - |
| Adds liveliness | 6 | + |
| Playful | 3 | + |
| Freedom | 2 | + |
| Grass increases (mental) health | 1 | + |

The attribute levels of trees were the amount, varying between few and many trees, and the clustering, varying between many and spread. Similar to the elaborations given on the presence of grass, trees were mentioned to provide a positive contrast to the urban design as well. Looking at Table 21, the participants were somewhat divided on the preferred attribute levels regarding trees, as many trees were found to be overwhelming by five of the 32 participants. Fewer trees made four participants feel safer. On the other hand, participants indicated that the presence of trees made the area livelier and more comfortable. Additionally, some participants pinpointed that the trees provided shelter against the sun and the tall buildings.

*Table 21 Answers to environmental attributes influencing user-experience: Trees*

| Summary | Count | Effect |
|---|---|---|
| Contrasts the urban environment | 9 | + |
| Preference for many trees | 8 | |
| Add liveliness | 6 | + |
| Many trees are overwhelming | 5 | - |
| Preference for spread | 5 | |
| Provide shelter | 4 | + |
| Preference for clustering | 4 | |
| Fewer trees feel safer | 4 | + |
| Preference for fewer trees | 4 | |
| Add comfort | 3 | + |

Water was added in the form of fountains in four of the environments. Half of the participants indicated that they thought of the fountains to be a fun addition to the area, as can be seen in Table 22. Four of them pointed out that the walking path leads to a square in the city centre which also has fountains, and they liked the parallel. A total of six participants indicated that they found the addition of fountains to be unnecessary. Additionally, five participants mentioned that the fountains affected their experience negatively, as it limits the walkability of the area.

*Table 22 Answers to environmental attributes influencing user-experience: Water*

| Summary | Count | Effect |
|---|---|---|
| Fun | 14 | + |
| Dynamic | 8 | + |
| Not necessary | 6 | |
| Limit walkability | 5 | - |
| Connects with fountains in city centre | 4 | + |
| Comforting | 2 | + |

#### 4.2.2.3 *Opinions and optimisations*

Besides their opinion on the separate attributes, participants were asked about their opinions on the redevelopment, as well as their suggestions for design optimisations.

The most often mentioned opinion was that greenery does have an added value, which is often overlooked in urban environments. Nine participants pointed out that greenery could be used to define use of space, by lining the walking path and creating a separation between high-traffic areas and space for relaxation. This is related to the preference for recreational greenery, by seventeen of the participants. In the models, there were no benches added, however, eight participants indicated that the presence of benches or places to sit down would contribute positively to their experience. All opinions and optimisations expressed are summarised in Tables 23 and 24.

*Table 23 Formed opinions*

| **Summary Opinion** | ***Count*** | ***Effect*** |
|---|---|---|
| Greenery has an added value | 18 | + |
| Buildings too tall for context | 7 | - |
| Use of space important | 5 | + |
| Open areas are necessary | 5 | + |
| Prefer view of the sky, less shadows | 4 | + |
| View on landmarks important | 3 | + |
| Content with placement of buildings | 1 | + |

*Table 24 Mentioned optimisations*

| **Summary Optimisation** | ***Count*** | ***Effect*** |
|---|---|---|
| Recreational greenery | 17 | + |
| Greenery to define use of space | 9 | + |
| Add benches and seating areas | 8 | + |
| Walkability is important | 7 | + |
| Lower building height | 4 | + |
| Public plinth | 4 | + |
| Create more space in between buildings | 2 | + |
| More open spaces | 2 | + |

### 4.2.3 Experiences in VR

Lastly, the participants were asked about their experiences in VR. This question was asked to gain insight in their experiences in VR, as it is part of this research question. As mentioned in the sample description of section 4.1, 22 out of the 32 participants have used a head-mounted display before. In general, the feedback given on the VR experience was positive. Eight participants indicated that they liked to be being fully immersed in the area, as if they were walking through it in real life. Next to that, seven participants mentioned that the VR experiment had an explorative character, which contributed positively to their experience. Moreover, fun and realistic were mentioned by several participants to describe their experiences. Three participants found the equipment straightforward to use and the term realistic was used by three participants to describe their view. On the other hand, not all experiences were completely positive. Six participants pointed out that the headset distorted their view to some extent, which affected their experience negatively. One participant found the experiment to be disorienting. All descriptions are summarised in Table 25.

*Table 25 Terms used to describe VR experience*

| ***Summary*** | ***Count*** | ***Effect*** |
|---|---|---|
| *Fully immersed* | 8 | + |
| *Fun* | 8 | + |
| *Explorative* | 7 | + |
| *Distorted view* | 6 | - |
| *Freedom* | 3 | + |
| *Straightforward* | 3 | + |
| *Realistic* | 3 | + |
| *Disorienting* | 1 | - |

### 4.3 Position Analysis

The Unity models included several scripts, among them the position analysis script. This script saved the X-, Y-, and Z-position of the participants per half a second in a csv file. This data could be used to create heatmaps in MATLAB. These heatmaps tell something about the places in the model participants tend to move through often, stand still or return to.

A MATLAB script was written using the histogram2 function. The script can be found in Appendix E. The plotted graphs were then projected over the maps of the corresponding Models. Figure 56 till Figure 64 show the heatmaps of all models together, and each model individually respectively. The indigo colour indicates that the coordinates have been visited limitedly, as spots are visited more often the colours shift along the colour bar to  blue, green, yellow, orange, and red for most visited.

Figure 56 is representing all data collected for the position analysis. The spot where each participant started, is indicated in red, as this is the same spot for every participant and every model. The space around it is light blue, indicating that the spot was visited often. As everybody is moving from the same point, this make sense, as the options for spots to visit next are converging. Next to that, participants needed some time to figure out where they were able to go in the model and to orient themselves. The main path from the station to the city centre  is lighter blue, indicating that most people choose to solely walk this path. Along the path there are several lighter spots, such as all the way to the left, at the edge of the transportation area and the square in front of the station, just before the statue. During the experiments it was noticed that people tend to first walk all the way to the left side, to the crossing to the city centre, as the square is recognizable for them. They spend some time looking at the square before turning around and taking in the redevelopment. Some then choose to walk around the square in the middle of the high-rise buildings, yet most choose to return to the square in front of the station and compare the outside perspectives.

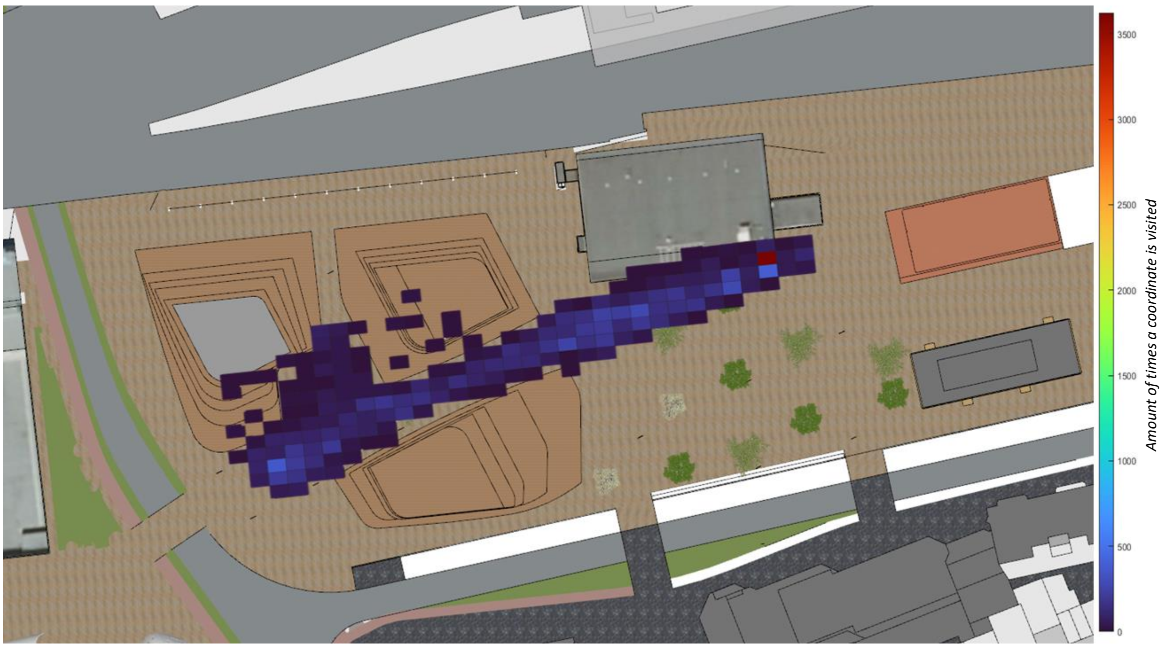


*Figure 56 Heatmap of Movement through All Models*

Looking at the heatmaps of the models individually, differences between the models can be noticed instantly. The heatmaps of Model 1 and Model 6, Figure 57 and 62 respectively, light blue spots immediately stand out. In Figure 58, which represents Model 2, it can be noticed that participants did not decide to walk on the square in between the buildings.

Looking back at Table 4, it can be noticed that Model 1, Model 2, and Model 6 all have skyscrapers. The height of the buildings in Model 2 and Model 6 are similar, whereas the height of the skyscrapers in Model 1 vary. Model 1 has an active façade, while Model 2 and Model 6 have a blank façade and in Model 2 some grass fields are included, contrary to the other two models. All three models are characterized by few trees, which are spread in Model 1 and Model 2, and Clustering in Model 6. Finally, Model 2 contains fountains, yet Model 1 and Model 6 do not.

Returning to the heatmaps, some of the attribute levels could explain the patterns of the three models. The most visit spots of Model 1 are the square in front of the station and the crossing to the city centre. One often mentioned characteristic, in the answers to the interview and open questions, was that the trees were lining the way to the city centre, which indicated the route intuitively. As the trees were indicating the routing, and there was not necessarily a place to rest in the model itself, participants were drawn to the edge of the redevelopment plan. When they arrived at the crossing, familiar buildings caught their eye, and they would not be able to move closer to the square, thus spending more time at the edge of the model. Additionally, in the models with skyscrapers it was often indicated that the buildings were too tall and the sense of scale was missing. Which indicates that participants would choose to spend less time in between the buildings, and more time in the more open areas, such as the square in between the buildings and the square in front of the station. As the square in between the buildings is still enclosed by skyscrapers, participants would return to the station square.

Then, zooming in on Figure 60, participants moved from the station to the crossing with the city centre. They were not drawn onto the square in between the buildings, as they were in Model 1. An explanation for this could be the layout of the grass and the presence of the fountains on the grass area. It was mentioned, in the interview and open questions, that the grass interfered with the routing, having participants either choose the left or right side of the grass to continue their path. The fountains in the middle could function as an extra barrier, keeping them on the same path from the station to the city centre and back.

*Figure 57 Heatmap of Movement through Model 1*

*Figure 58 Heatmap of Movement through Model 2*


*Figure 59  Heatmap of Movement through Model 3*


*Figure 60  Heatmap of Movement through Model 4*

The main highlights in Model 6 are oriented around the square in front of the station, as the left side of the map is less visited. Besides the height of the buildings, it was mentioned that there were a lot of trees. Similar to Model 1, the buildings were considered very tall, the sense of scale missing and there were many trees. Multiple participants described their experience as “feeling surrounded” and “feeling pushed out”. The heatmap of positions can be related to these experiences, did not walk all the way to the crossing with the city centre or spend time in between the buildings. Instead, they tend to spend their time on the square in front of the station, where they have a bit more overview and are not enclosed by the buildings.


*Figure 61  Heatmap of Movement through Model 5*


*Figure 62  Heatmap of Movement through Model 6*


*Figure 63  Heatmap of Movement through Model 7*


*Figure 64  Heatmap of Movement through Model 8*

### 4.4 Eye-data Analysis

This section will focus on the analysis of the eye-data observations. The eye-data was gathered during the experiments as a csv file with the position and rotation of the headset, with a frequency of twice per second, and another script saved the interactions between the cylinder connected to the headset and the collider objects representing the varied attributes.

#### 4.4.1 Gaze Points and Scan Paths

When counting all gaze points on attributes of the HMD view, most hits were with the trees, as visualised in Figure 65. This could be explained by the trees being present on the teleportation area, as well as on the station square. Next to that, trees are larger objects and were present in all models.

The second most viewed attribute is the façade. Most interactions with the façade were in models 1 and 7, which have an active façade. Model 3 and 4, which also have active façades, did have less interactions with the façades, as they had more interactions with trees. Looking at the plots of the HMD rotation, there is not necessarily a different pattern to be recognized. Models 1 and 7 had few trees, whereas models 3 and 4 had many trees. This indicates that rather than consciously looking at trees more often, trees were blocking the view to other attributes.

Next to that, it could be noticed that the number of gaze points the grass in Model 7 is a lot more than the other models with grass. Besides the active façade and few clustered trees, this model is characterized by a high-rise building height with no height variation, and no fountains. Besides the active façade, there is little going on at eye-level in this model, following Figure 66, Model 7 counted 17 interactions between façade and grass, which supports this argument.

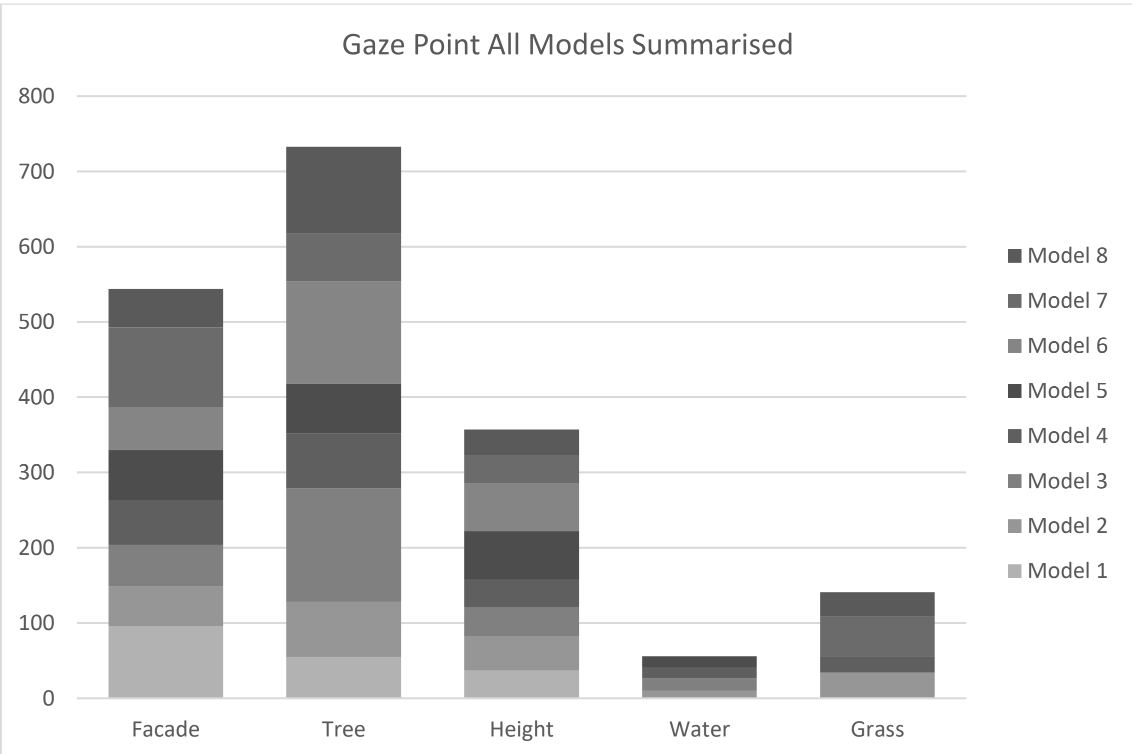


*Figure 65 Gaze Points per model summarised*

The most occurring scan path is from trees to façades. Both are at eye-level, which makes it easier to transfer between the two. Model 6 has blank façades, which contributes to the façade count similar to the other model. However, when looking at the scan paths, 21 of the 57 interactions were a sequence between tree and façade. According to the literature review, blank façades are less likely to hold the attention of viewers, compared to active façades. This could explain the participants' switch between the blank façades and the trees, which are more detailed.

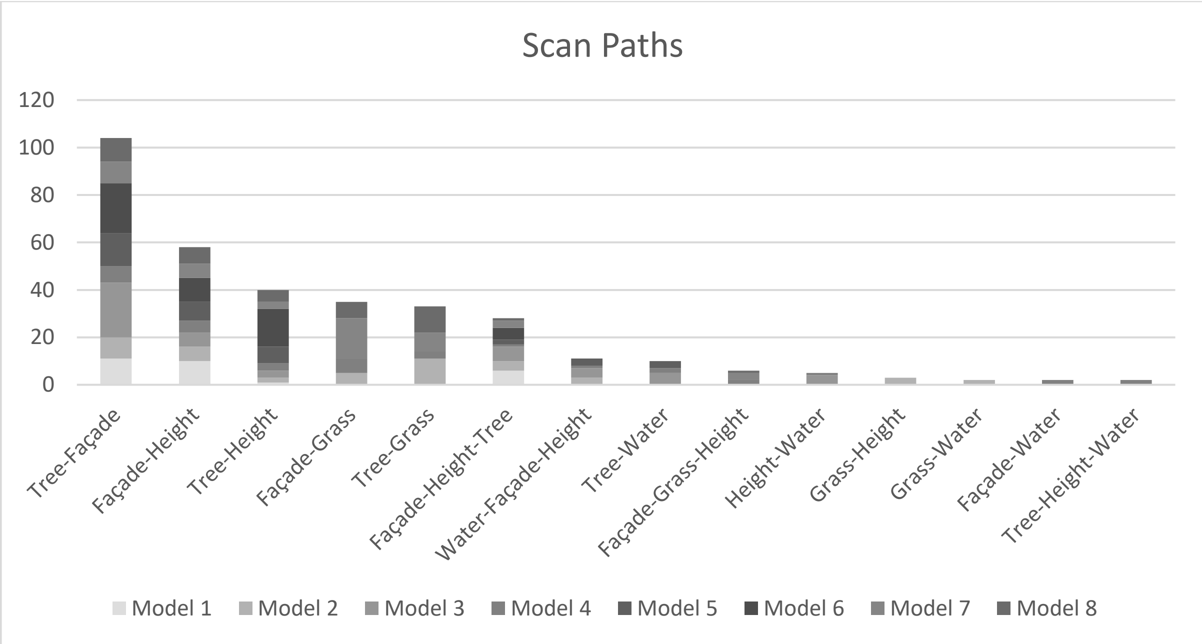


*Figure 66 Scan Paths per model summarised*

### 4.4.2 Rotation data

Furthermore, the rotation of the headset is visualised and analysed using MATLAB. These 3D plots will give an impression of the locations in the models where the participants decided to stand still and look around. De positions are indicated using the black dots, the spikes emerging from these dots indicate the rotation of the player, thus visualising the direction of vision. These plots are projected over a map of the model, to get a better understanding of the environment. The MATLAB script for this analysis is included in Appendix F.

From the position analysis of Model 1 followed that most time was spent just in front of the high-rise buildings at the station square, and at the end of the transportation area, near the crossing to the city centre. This is also visible in Figure 67 as the position dots in these areas have a lot of spikes sprouting from them. Participants stopped at these spots to look around, not only to the landmarks and other point of recognition, but also to take in the different elevations of the redevelopment. In between the two buildings in the walking path from the station to the city centre, participants tended to view only the path, and did not look around that much, which coincides the position analysis. The height of the buildings was mostly viewed from the edges of the redevelopment area of the three buildings.

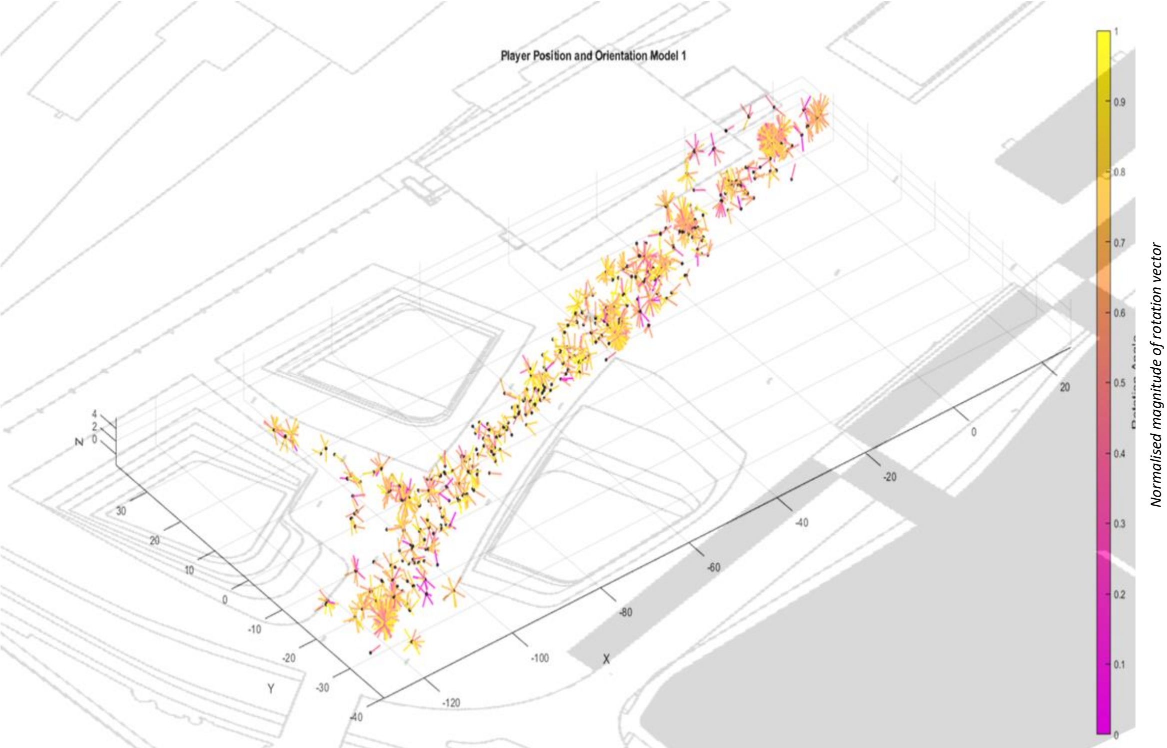


*Figure 67 Visualisation of position and rotation in Model 1*

In the second model, grass was added. When comparing the plot to the plot of Model 1, it can be seen that the participants moved around the grass and had more interactions with the grass and fountains, as the angle of the HMD was rotated downwards around these attributes, as can be seen in Figure 68.

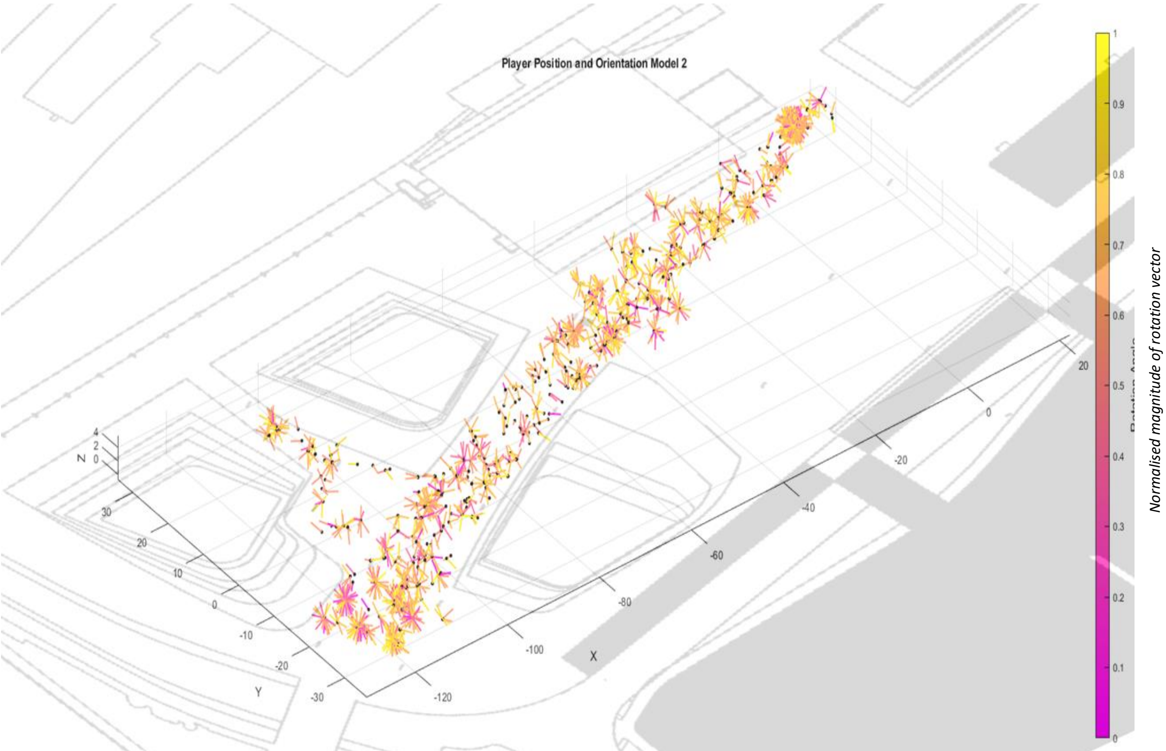


*Figure 68 Visualisation of position and rotation in Model 2*

The third model was characterized by many spread trees. There were a lot of interactions with the trees and participants were looking for spaces they could spend time without trees surrounding them. This explains the many rotations all the way to the right of the plot, next to the station, and the orientation towards the city centre at the left side of the plot, as can be seen in Figure 69.

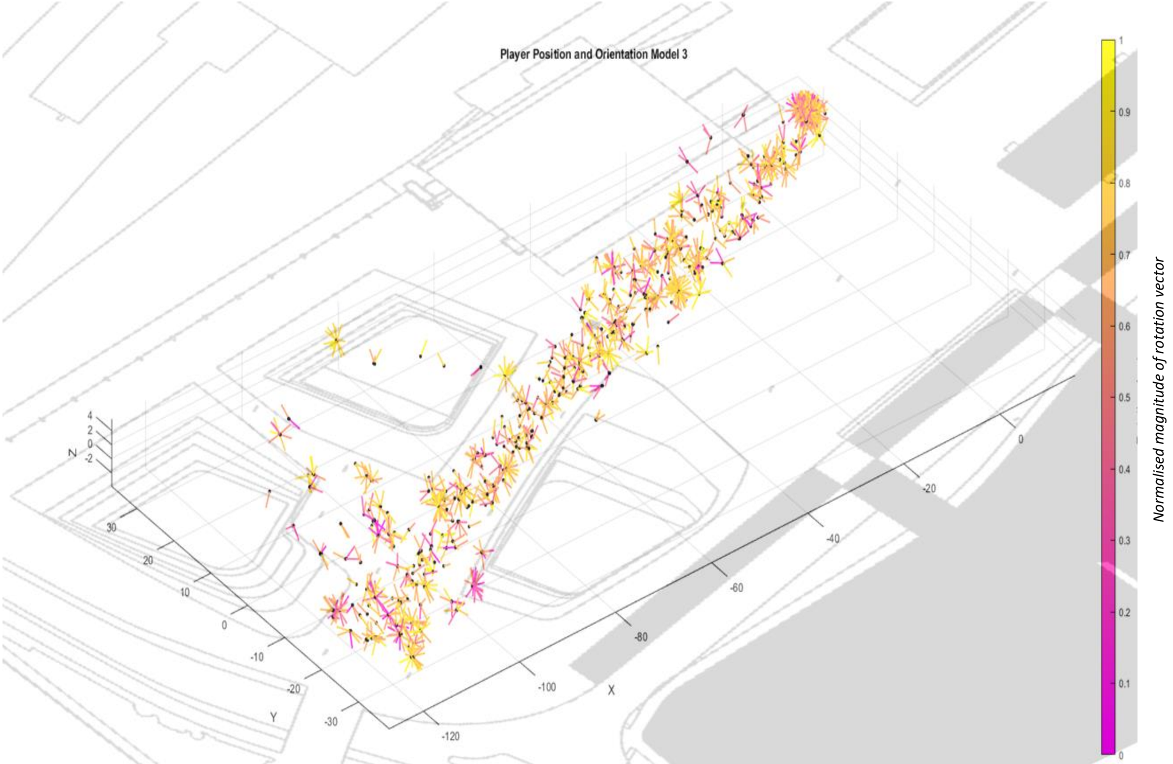


*Figure 69 Visualisation of position and rotation in Model 3*

When visiting Model 4, people did not necessarily look around the smaller square in the middle of the three new buildings. The alley towards the train track, on the other hand, was visited and participants looked around there. Next to that, the participants spent some time looking around the station square, taking in the park. Yet nothing really caught the participants' attention, following from Figure 70.


*Figure 70 Visualisation of position and rotation in Model 4*

The rotation plots of the fifth model, Figure 71, show two areas where participants decided to look around. All the way at the left side of the model, towards the crossing to the city centre, multiple spikes in all directions are present. The second area is all the way at the right of the plot, at the right side of the station. The interaction counts of Model 5 are characterized by approximately equal numbers for the interaction with the façades, trees, and heights. The buildings are high-rise with height variations, which result in the lowest buildings compared to the other models. These heights are especially watched from the areas discussed above. The façades are blank and the few trees are clustered, which are viewed from the walking path. Yet nothing really held the participants attention.

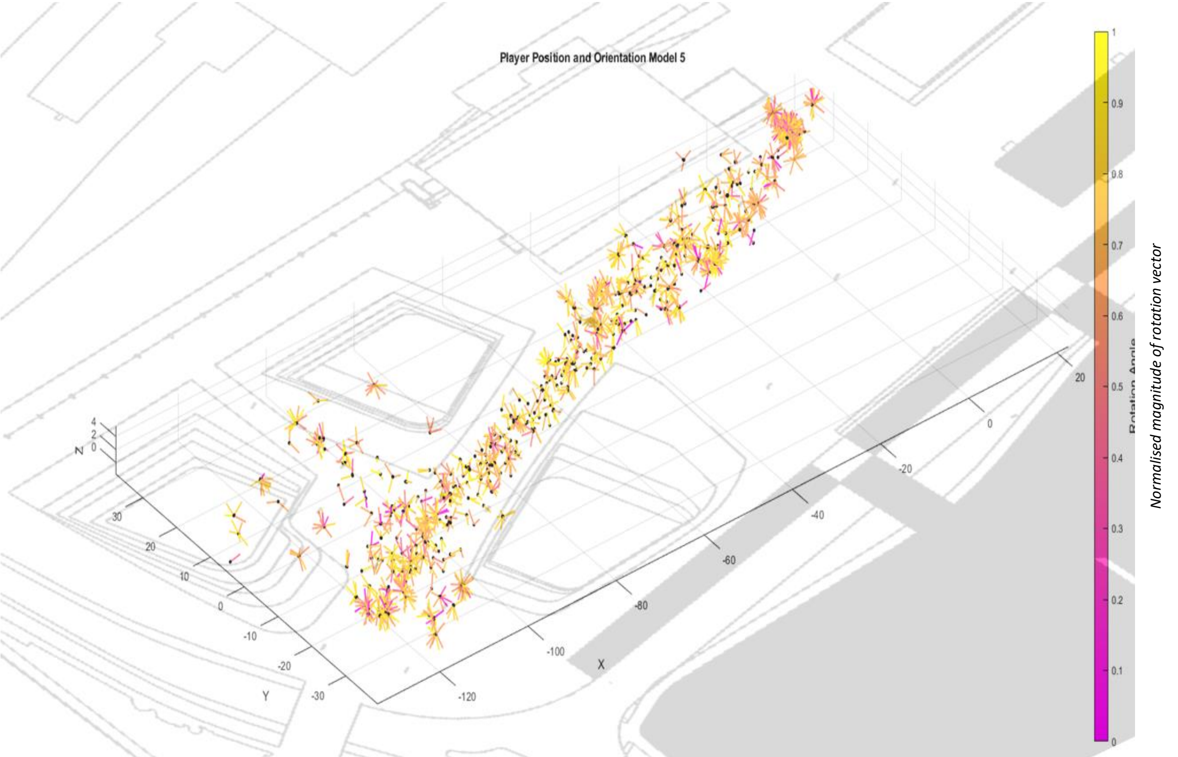


*Figure 71 Visualisation of position and rotation in Model 5*


*Figure 72 Visualisation of position and rotation in Model 6*


*Figure 73 Visualisation of position and rotation in Model 7*

In the rotation plot of Model 8, Figure 74, the effect of the placement of grass can be recognised. Participants looked down to the grass to make sure to walk around it, rather than stepping onto it. Most of the interactions with the grass, were separately or in a sequence with a façade or tree. The model included many trees, which are surrounding the grass fields, further explaining the avoidance of stepping on the grass and the interactions. The façades in this model, which was found earlier to not really hold the attention of the participants. Together with the walking path, this scan path be explained by the spikes in the walking path indicating that participants navigated by looking from the façade to the grass and/or the other way around.

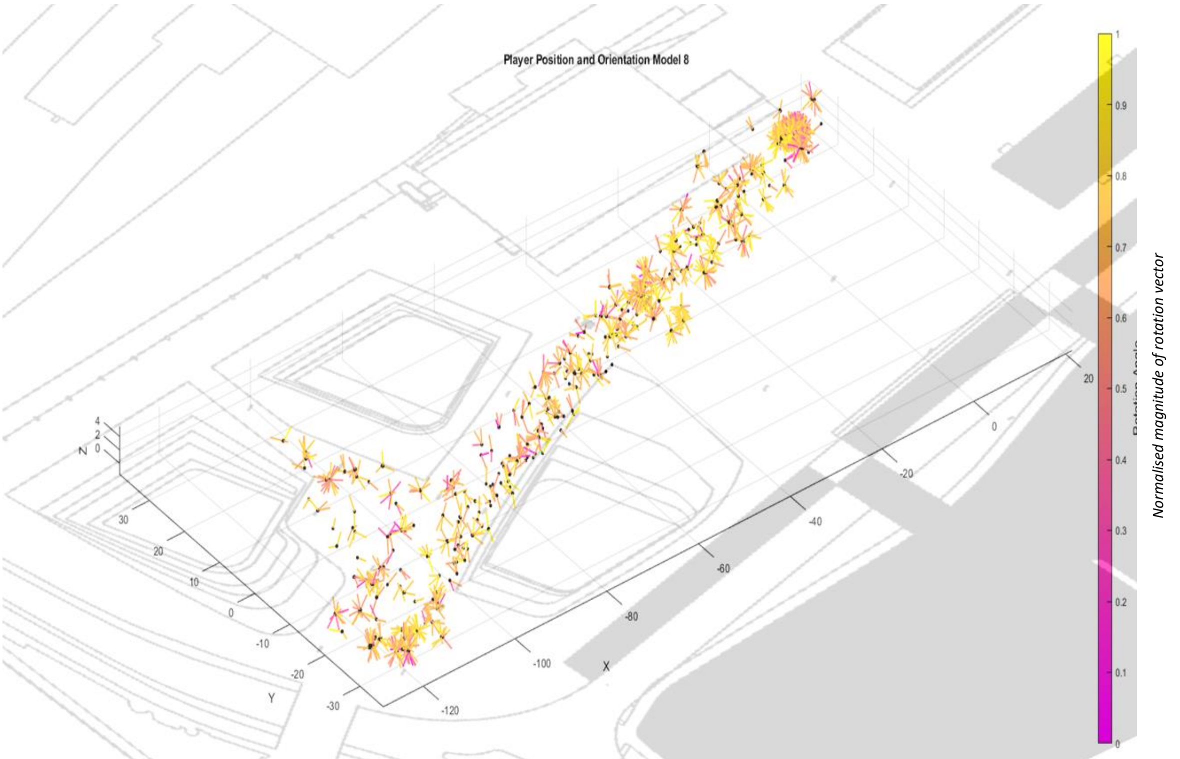


*Figure 74 Visualisation of position and rotation in Model 8*

## 4.5 Influence of Environmental Characteristics on User-experience

The last section of this chapter aims to answer the research question: "*What characteristics of high-rise areas influence the user-experience, when modelled in an immersive virtual environment and using eye-tracking?".*

### 4.5.1 Data preparation

To do so, the data was prepared and coded using excel. This included removing the open questions from the dataset, coding all the closed questions to numerical values, using a dichotomous or ordinal level of measurement, merging some of the variables into a new one, and adding in the variables describing the characteristics of the environment according to the corresponding model into the dataset.

As mentioned in the description of the sample at the beginning of this chapter, the Cronbach's Alpha was calculated for the variables describing the mood of the participant before the experiment. The Cronbach's Alpha was larger than 0.7, thus the four variables could be combined into Mood, measured on a scale level. The user-experience variables safety, comfort and happiness indicated with a higher score a more positive experience, whereas the variable annoyance indicated a more negative experienced with a higher score. Therefore, similar to mood, the scores were inverted and a new variable *Pleasure* was created. The same test was applied to the variables *Safe, Comfort, Pleasure*, and *Happiness*, for the first, second and third visited model, respectively. To the outcomes of these tests applied if the Cronbach's Alpha calculated was larger than 0.7, the four variables could be merged into one describing the user-experience of the first, second or third model visited. The calculated values for the Cronbach's Alpha for each of the three sets of user-experience variables are described in Table 26.

*Table 26 Calculated Cronbach's Alpha for the User-experience Variables of the First, Second and Third Visited Models*

| ***Reliability Statistics*** | *Cronbach's Alpha* | *Cronbach's Alpha Based on Standardized Items* | *N of Items* |
|---|---|---|---|
| *First visited models* | 0.862 | 0.863 | 4 |
| *Second visited models* | 0.881 | 0.889 | 4 |
| *Third visited models* | 0.822 | 0.824 | 4 |

From the table it could be concluded that all three values are higher than 0.7, thus the four variables *Safety, Comfort, Pleasure*, and *Happiness* could be combined to user-experience First Model, user-experience Second Model and user-experience Third Model. To calculate the values of these new variables, the average of the 4 merged variables was taken, thus the new variables are measured on a scale level, where a higher score indicates a higher user-experience. Table 27 includes the descriptive statistics of the newly created variables. The first visit to a VR model has the highest score on user-experience wit ha mean of 3.8125 and a standard deviation of 0.66901. The standard deviation of the user-experience of the first visited models is the lowest compared to the other two variables.

*Table 27 Descriptive Statistics of User-experience of the first, second and third visited model*

| ***Descriptive Statistics*** | *N* | *Minimum* | *Maximum* | *Mean* | *Std. Deviation* |
|---|---|---|---|---|---|
| *User-experience First Model* | 32 | 2.75 | 5.00 | 3.8125 | 0.66901 |
| *User-experience Second Model* | 32 | 2.00 | 5.00 | 3.6562 | 0.77966 |
| *User-experience Third Model* | 32 | 2.25 | 4.75 | 3.7344 | 0.67183 |

To determine the mood and the user-experience, the same four questions were asked, and the average was taken to create one new variable for the mood and the user-experience, respectively. From the descriptive tables it can be concluded that the mood at the beginning of the experiments was quite positive, with a mean value of 4.13, the user-experience after visiting the first model equals 3.81 and decreases after the visit to the second model. After the third model, the mean user-experience is a bit more positive than after the second model, but still not as possible as the mood in the beginning or the user-experience after visiting the first model. This trend is also seen in the line charts of Figures 75, 76 and 77.

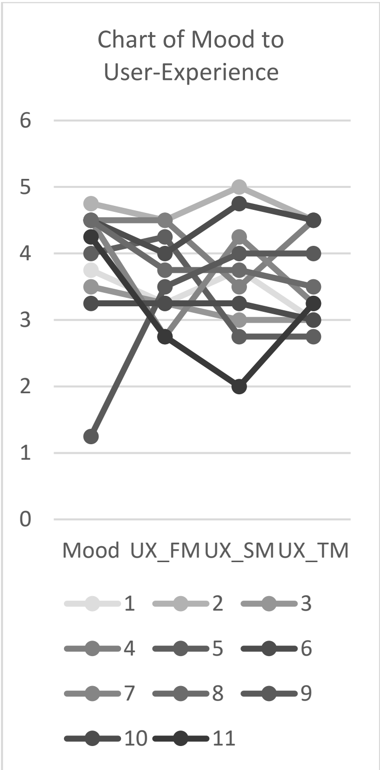


*Figure 75 Line chart of mood to user-experience participants 1 to 11*

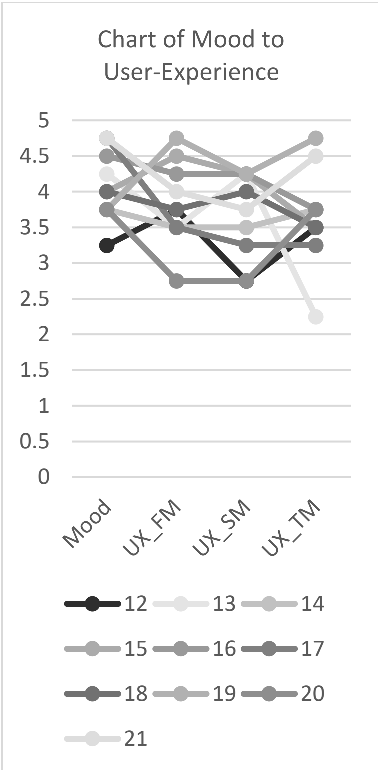


*Figure 76 Line chart of mood to user-experience participants 12 to 21*

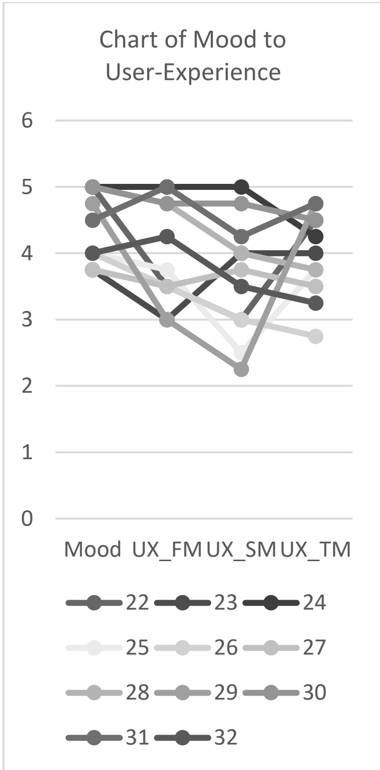


*Figure 77 Line chart of mood to user-experience participants 22 to 32*

### 4.5.2 Regression analysis first visited models.

The environments of the different models were designed according to orthogonal experimental design principles, which ensures that each independent variable's effect can be isolated and analysed independently of the others. Therefore, it is not necessary to conduct a correlation analysis. In order to conduct a regression analysis, the conditions and assumptions have to be met. The conditions and assumptions are as follows:

1. Sample size should be larger than 30;
2. Levels of measurement of the:
    a. Dependent variable should be interval, ratio or continuous;
    b. Independent variables should be interval, ratio, nominal (dichotomous; otherwise dummies); ordinal: only Likert items, normal distribution;
3. There are no outliers;
4. Missing values should be declared and deleted;
5. Linear relations between the dependent variable and independent variables;
6. Independent observations;
7. Normal distribution of residuals;
8. No multicollinearity;
9. Homoscedasticity.

32 people participated and each viewed three models, having a total of 96 measurements, the first condition is met. The dependent variable is continuous and the independent variables are dichotomous, meaning that the second condition is met as well. In order to check the third condition, boxplots were analysed where the independent variables are on the X-axis and the dependent variable on the Y-axis. These plots can be found in Appendix G. From the boxplots it can be concluded only participant 28 has indicated a user-experience higher than the range on the boxplot of Water and User-experience. Furthermore, there were no missing values.

The models were created using orthogonal design, thus all variables could be entered at once in a regression analysis. A linear regression was run using SPSS, using the method “Enter”, for all regression analyses. Besides the model summary, ANOVA, and coefficients tables, also a histogram of the residuals was plotted to check the normal distribution, as well as a scatterplot to check homoscedasticity.

For the first visited models, the façade type and the presence of water are significant, however, the other independent variables are not, as can be derived from the coefficients table in Table 31. This table suggest that models with a blank façade instead of an active façade have a higher user-experience. For the presence of water, the value is negative, indicating that the user-experience is higher if there is water present. The R Square value equals 0.527, as can be seen in the model summary in Table 28, which means that only 52.7% of the user-experience of the first visited models can be explained by the type of façade and the presence of water. The histogram of residuals, Figure 78, does follow the normal distribution, thus point 7 of the regression analysis conditions and assumptions is met. The scatterplot “zpred - zresid”, Figure 79, does not have an odd shape, thus the assumption of homoscedasticity may hold in the regression model.

*Table 28 Model summary regression first visited models*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| *1* | ,726[a] | ,527 | ,389 | ,52291 |

*Table 29 ANOVA first visited models*

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 7,313 | 7 | 1,045 | 3,820 | ,006 |
| | Residual | 6,563 | 24 | ,273 | | |
| | Total | 13,875 | 31 | | | |

*Table 30 Coefficients table first visited models*

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3,688 | ,261 | | 14,104 | <,001 |
| | FIRST VISIT_Height | ,375 | ,185 | ,285 | 2,028 | ,054 |
| | FIRST VISIT_Height Variation | ,156 | ,185 | ,119 | ,845 | ,406 |
| | FIRST VISIT_Façade | ,406 | ,185 | ,308 | 2,197 | ,038 |
| | FIRST VISIT_Grass | -,250 | ,185 | -,190 | -1,352 | ,189 |
| | FIRST VISIT_Trees | ,219 | ,185 | ,166 | 1,183 | ,248 |
| | FIRST VISIT_Clustering | ,031 | ,185 | ,024 | ,169 | ,867 |
| | FIRST VISIT_Water | -,688 | ,185 | -,522 | -3,719 | ,001 |

a. Dependent Variable: UX_FIRST VISIT

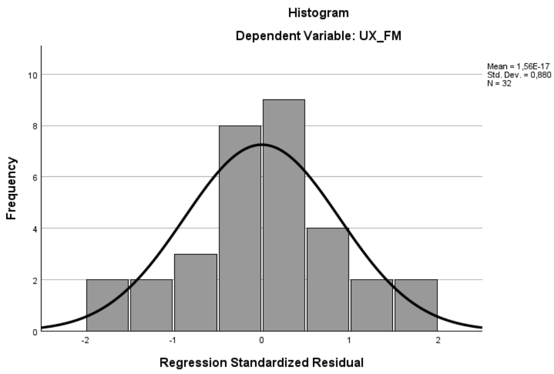


*Figure 78 Histogram of residuals first visited models*

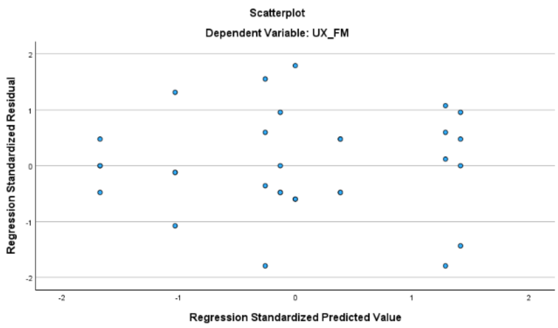


*Figure 79 The scatterplot “zpred - zresid” of first visited models*

### 4.5.3 Regression analysis second visited models

For the second visited models, none of the independent variables are significant, as can be derived from the coefficients table in Table 33. This table suggest that the user-experience cannot be explained by the environmental characteristics. The R Square value equals 0.098, as can be seen in the model summary in Table 31, which means that only 9.8% of the user-experience of the second visited models can be explained by independent variables. The histogram of residuals, Figure 80, does not follow the normal distribution, as there is an outlier, thus point 7 of the regression analysis conditions and assumptions cannot be met. The scatterplot “zpred - zresid”, in Figure 81, does have an odd, diabolo-like shape, thus the assumption of homoscedasticity does not hold in the regression model.

*Table 31 Model summary of regression second visited models*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| *1* | ,313[a] | ,098 | -.165 | .84163 |

*Table 32 ANOVA of second visited models*

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.844 | 7 | `.263 | .372 | ,910[b] |
| | Residual | 17.000 | 24 | .708 | | |
| | Total | 18.844 | 31 | | | |

*Table 33 Coefficients table regression second visited models*

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3,625 | ,421 | | 8,614 | <,001 |
| | SECOND VISIT_Height | ,094 | ,298 | ,061 | ,315 | ,755 |
| | SECOND VISIT_Height Variation | ,313 | ,298 | ,204 | 1,050 | ,304 |
| | SECOND VISIT_Façade | ,031 | ,298 | ,020 | ,105 | ,917 |
| | SECOND VISIT_Grass | -,125 | ,298 | -,081 | -,420 | ,678 |
| | SECOND VISIT_Trees | -,313 | ,298 | -,204 | - 1,050 | ,304 |
| | SECOND VISIT_Clustering | ,094 | ,298 | ,061 | ,315 | ,755 |
| | SECOND VISIT_Water | -,031 | ,298 | -,020 | -,105 | ,917 |

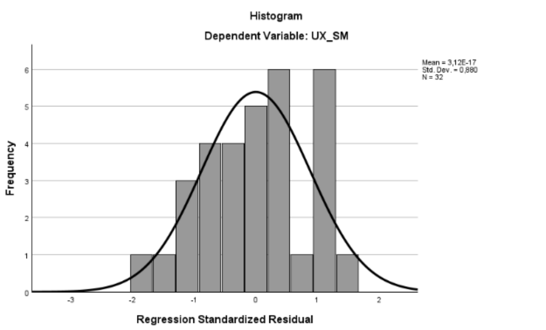


*Figure 80 Histogram of residuals second visited models*

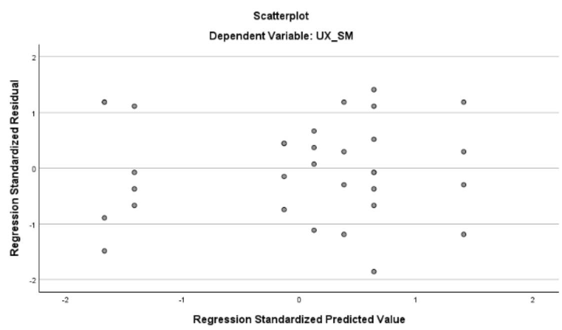


*Figure 81 The scatterplot “zpred - zresid” of second visited models*

### 4.5.4 Regression analysis third visited models

For the third visited models, none of the independent variables are significant, as can be derived from the coefficients Table 36. This table suggest that the user-experience cannot be explained by the environmental characteristics. The R Square value equals 0.133, as can be seen in the model summary in Table 34, which means that only 13.3% of the user-experience of the second visited models can be explained by independent variables. The histogram of residuals, Figure 82, does not follow the normal distribution, as there is an outlier, thus point 7 of the regression analysis conditions and assumptions cannot be met. The scatterplot "zpred - zresid" in Figure 83 does have an odd shape, thus the assumption of homoscedasticity does not hold in the regression model.

*Table 34 Model summary of regression third visited models*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| *1* | ,365[a] | .133 | -.119 | .71078 |

*Table 35 ANOVA of third visited models*

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 1,867 | 7 | ,267 | .528 | ,805 |
| | Residual | 12,125 | 24 | ,505 | | |
| | Total | 13,992 | 31 | | | |

*Table 36 Coefficients table regression third visited models*

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3,875 | ,355 | | 10,904 | <,001 |
| | THIRD VISIT_Height | -,063 | ,251 | -,047 | -,249 | ,806 |
| | THIRD VISIT_Height Variation | ,156 | ,251 | ,118 | ,622 | ,540 |
| | THIRD VISIT_Façade | -,187 | ,251 | -,142 | -,746 | ,463 |
| | THIRD VISIT_Grass | ,063 | ,251 | ,047 | ,249 | ,806 |
| | THIRD VISIT_Trees | -,375 | ,251 | -,284 | -1,492 | ,149 |
| | THIRD VISIT_Clustering | -,031 | ,251 | -,024 | -,124 | ,902 |
| | THIRD VISIT_Water | ,156 | ,251 | ,118 | ,622 | ,540 |

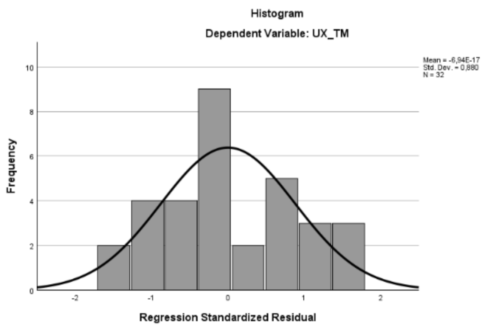


*Figure 82 Histogram of residuals third visited models*

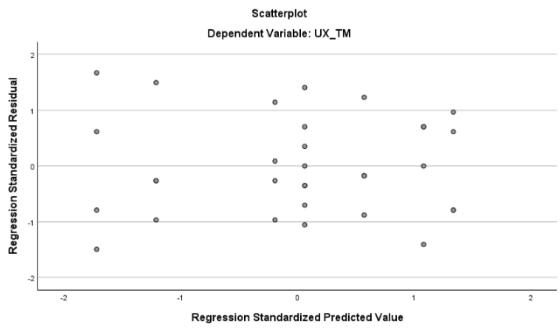


*Figure 83 The scatterplot "zpred - zresid" of third visited models*

### 4.5.5 Regression analysis all cases

Then a linear regression was run using SPSS, for the User-experience variables of all 96 cases together. Besides the model summary, ANOVA, and coefficients tables, also a histogram of the residuals was plotted to check the normal distribution, as well as a scatterplot to check homoscedasticity.

For the combined dataset, none of the independent variables are significant, as can be derived from the coefficients table. Table 39 suggest that the user-experience cannot be explained by the environmental characteristics. The R Square value equals 0.071, as can be seen in the model summary in Table 37, which means that only 7.1% of the user-experience can be explained by independent variables. The histogram of residuals does not follow the normal distribution, as there is an outlier, thus point 7 of the regression analysis conditions and assumptions cannot be met. The scatterplot "zpred - zresid" does have an odd shape, thus the assumption of homoscedasticity does not hold in the regression model.

*Table 37 Model summary 96 cases*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| *1* | ,267[a] | ,071 | -,002 | ,70501 |

*Table 38 ANOVA 96 cases*

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 3,362 | 7 | ,480 | ,966 | ,461 |
| | Residual | 43,740 | 88 | ,497 | | |
| | Total | 47,102 | 95 | | | |

*Table 39 Coefficient table 96 cases*

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3,729 | ,204 | | 18,323 | <,001 |
| | THIRD VISIT_Height | ,135 | ,144 | ,097 | ,941 | ,349 |
| | THIRD VISIT_Height Variation | ,208 | ,144 | ,149 | 1,448 | ,151 |
| | THIRD VISIT_Façade | ,083 | ,144 | ,059 | ,579 | ,564 |
| | THIRD VISIT_Grass | -,104 | ,144 | -,074 | -,724 | ,471 |
| | THIRD VISIT_Trees | -,156 | ,144 | -,112 | -1,086 | ,281 |
| | THIRD VISIT_Clustering | ,031 | ,144 | ,022 | ,217 | ,829 |
| | THIRD VISIT_Water | -,187 | ,144 | -,134 | -1,303 | ,196 |

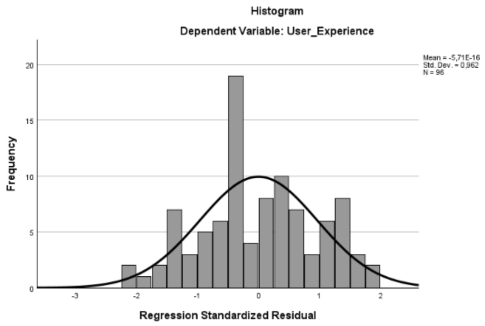


*Figure 84 Histogram of residuals 96 cases*

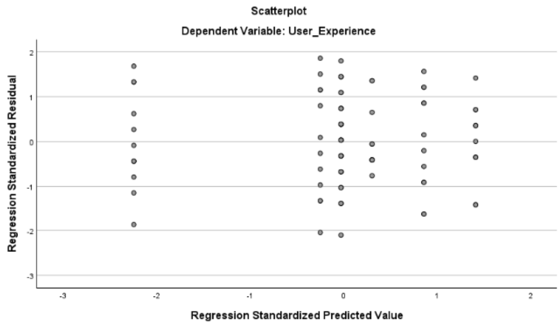


*Figure 85 The scatterplot “zpred - zresid” of 96 cases*

### 4.5.6 Fixed Effects Panel Regression

In the preceding regression analysis, which included all 96 ratings of user-experience, it was not considered that there were only 32 participants, which had their user-experience measured three moments in time. A fixed effects regression could be applied to this dataset, as individual-specific attributes remain constant across the three instances of user-experience assessment, thus qualifying as fixed effects (Brüderl & Ludwig, 2015).

First, a variable was added to the dataset, indicating whether the user-experience value corresponded to the first, second or third visited model. Then the dataset was sorted by participant number and visit. To be able to execute the fixed effects panel regression in SPSS, a dummy variable was created for each of the participant numbers. Then a linear regression analysis was selected, with the dummy variables of the participant numbers, minus the dummy for the first participant, in the first regression model. In the second regression model, the environmental characteristics were added. This is summarised in Table 40.

*Table 40 Variables entered/removed in two models of the panel regression*

**Variables Entered/Removed**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | ID=32.0, ID=31.0, ID=30.0, ID=29.0, ID=28.0, ID=27.0, ID=26.0, ID=25.0, ID=24.0, ID=23.0, ID=22.0, ID=21.0, ID=20.0, ID=19.0, ID=18.0, ID=17.0, ID=16.0, ID=15.0, ID=14.0, ID=13.0, ID=12.0, ID=11.0, ID=10.0, ID=9.0, ID=8.0, ID=7.0, ID=6.0, ID=5.0, ID=4.0, ID=3.0, ID=2.0[b] | . | Enter |
| 2 | Façade, Grass, Clustering, Height, Trees, Water, Height Variation[b] | . | Enter |

From the model summary in Table 41, it follows that 61.6% of the variation in user-experience ratings is occurring between participants, as the R Square value of the first regression model equals .616. Looking at the R Square value of the second regression model, which equals .682, 68.2% of the variation in user-experience ratings is . It reflects the combined effect of the between group predictors and the time-variant predictors. The R Square value change from Model 1 to Model 2 equals 0.066, which means that the addition of the environmental variables accounts for an additional 6.6% of the variation. However, as can be seen in the F-test change, the change is not statistically significant.

*Table 41 Model summary of panel regression*

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics: R Square Change | F Change | df1 | df2 | Sig. F Change |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ,785[a] | ,616 | ,430 | ,53156 | ,616 | 3,313 | 31 | 64 | <,001 |
| 2 | ,826[b] | ,682 | ,469 | ,51294 | ,066 | 1,676 | 7 | 57 | ,133 |

*Table 42 ANOVA of panel regression*

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 29,018 | 31 | ,936 | 3,313 | <,001[b] |
| | Residual | 18,083 | 64 | ,283 | | |
| | Total | 47,102 | 95 | | | |
| 2 | Regression | 32,105 | 38 | ,845 | 3,211 | <,001[c] |
| | Residual | 14,997 | 57 | ,263 | | |
| | Total | 47,102 | 95 | | | |

Approximately 17% of the variation within person is accounted for by the environmental characteristics, following the calculation: $\frac{ChangeRsq}{1-Rsq} = \frac{.066}{1-.616} = .171875.$

The coefficients tables of the panel regression are included in Appendix H. The coefficient of the variable height is positive, which indicates that the high-rise building height increases the user-experience by .209. The height variation has a positive coefficient as well, which indicates that models with buildings with a similar building height result in a higher user-experience. The coefficients of façade, grass, trees, and water are negative. This suggests that blind walls, no grass, fewer trees, and no fountains result in a lower user-experience. Regarding the clustering of trees, the positive coefficient indicates that spread trees contributes positively to the user-experience, as opposed to clustered trees. However, none of the environmental variables would be considered significant at the .05 level.

Another method to conduct a fixed effects panel regression analysis using SPSS, is by selecting "general linear model > univariate" in SPSS. The user-experience stays the dependent variable, the participant number is selected as fixed factor and the environmental variables are added as covariates. For this analysis, the user-experience was computed by adding the four separate user-experience variables, rather than taking the average. When comparing the outcomes of the univariate linear model to the outcomes of the preceding linear regression model, the value of the Partial Eta Squared of the corrected model equals the R Squared value. The directions of the coefficients are the same, but the values differ, as the used user-experience values are computed differently. The significance of  independent variables is the same as well.

### 4.6 Conclusion

The aim of this chapter was to analyse all collected data during the experiments, to be able to answer the research questions. The data collection included personal characteristics, answers to open and interview questions, position and rotation data of the participant in the immersive virtual environment, gaze points and scan path data, and their user experience described on a 5-point Likert scale.

A total of 32 people participated in the experiments. All participants were recruited on the campus of Eindhoven University of Technology. Of the 32 participants, 13 identified as male and 19 identified as female. Most of them visit high-rise areas often. The mean of the participants personality could be described as somewhat arousal seeking, somewhat extrovert and having little tendency towards negative feelings. Of the 32 participants, 12 people indicated to have experienced some symptoms of cybersickness.

The open and interview questions were analysed using an open, descriptive coding method. The answers to the questions were summarized in tables, with the number of times the theme was mentioned, and whether a positive or negative relation to the user-experience was indicated. The most mentioned theme was the number of trees. Generally, the participants explained that having little trees affected their user-experience in a negative manner, as it was perceived as no trees being present. When there were a lot of trees, especially when they were spread, it became overwhelming and the trees were interfering with the walking path, which also affected the experience negatively. Next to that, the building height affected their experience negatively as well, as they described feeling pushed out of the area and missed the sense of scale in the models with higher buildings. The presence of grass added some relaxing features on eye level, but should not interfere with the walking path, which also applies to the addition of fountains. From the open and interview questions it could be concluded that the participants have a more positive user-experience in case of a lower building height, when grass and fountains are present, but not interfering with the walking path, and trees are present, but either few spread or many clustered.

In general, they had a positive experience using the VR headset, as they found being fully immersed in the model fun and explorative. However, a negative side of using immersive virtual reality is the distorted view, as a headset has only a small screen.

The data of the position analysis was visualised in heatmaps using MATLAB. The path from the station, which was the starting point, to the city centre was the most walked. Some of the attribute levels did explain the patterns recognised in the heatmaps. In models with grass and/or fountains, it could be recognised that participants intuitively walked around them. In models with skyscrapers, people tend to spend more time outside of the three buildings, on the edge of the model or on the station square, as the building height made them feel surrounded and pushed out.

From the gaze point analysis, it followed that the most viewed attribute is trees, followed by the façade. Logically, the most occurring scan path was between trees and façades. Additionally, most participants looked at the façade followed by the building height. From the rotation analysis can be concluded that in models with grass or fountains, participants were looking down more often.

Finally, several regression analyses were conducted, with the user-experience as dependent variable and the environmental characteristics as independent variables. In order to conduct the regression, one variable for user-experience was computed, taking the average of the scores of *Safety, Comfort, Pleasure (opposite of Annoyance)* and *Happiness*. At first a linear regression was run for the first, second and third visited models separately. From these analyses followed that only the type of façade and presence of water were significant in the first visited models. The other variables turned out to be not significant. From this followed that for the first visited models, the blank facades and presence of fountains positively influenced the user-experience. However, this did not apply to the second and third visited models. Looking at the scores of *Mood* and *User-Experience* throughout the models, it can be concluded that the mood at the start of the experiment was somewhat positive, the user-experience rating of the first visited models was the highest, followed by the third visited models, and the lowest for the second visited models. This could be related to a learning effect, or the first model being experienced as fun and exiting, whereas the second and third model felt more like a repetition.

Lastly, a fixed effects panel regression was conducted to account for variation in between an individual. Also, this model did not have any statistically significant variables.

## 5. Conclusion & Discussion

This research aimed to address the research gap for both using Immersive Virtual Environments to conduct research studies in the built environment and using eye-tracking techniques for measuring user-experience. The main research question of this study is: "*What characteristics of high-rise areas influence the user-experience, when modelled in an immersive virtual environment and using eye-tracking observations?".*

At first a literature review was conducted to define "user-experience" and gain insights in preceding research studies on the topic. From said literature review followed that there is no single definition for user-experience. In similar studies, four main emotions were used to describe user-experience: safety, comfort, annoyance, and happiness. Thus, user-experience was chosen to be defined as a positive or negative value, computed by merging the ratings on a 5-point Likert scale of the four main emotions.

The stimulus-organism-response model provided a framework which explained how people perceive their environments. From this framework it could be derived that, whilst the environment exists out of a lot of separate elements, people perceive it as a whole. Their previous experiences and personal characteristics function as response moderators, which influence their internal response to the environment and/or representation of the environment. Ultimately this leads to a certain behavioural response, such as an approach or avoidance behaviour.

Several characteristics of the built environment were found to influence the user-experience, but they were mostly mapped using qualitative research methods such as self-reporting and surveys. These characteristics included: building height, variation in building height, sense of scale, view of the sky, presence of daylight, number of buildings per block length, level of architectural detailing, presence of streetlighting, amount of grass, number of trees, clustering of trees and presence of water. Personal characteristics that could function as response moderators included age, gender, urbanisation level of living environment, frequency of visits to high-rise environments, personality, and mood. But, when looking at their environment, people tend to look at their path and obstacles in their path, faces and readable signs, before moving to façades and other attributes.

The attributes incorporated in the experiment were height of buildings, variation in building height, grass coverage, number of trees, clustering of trees and presence of water. Each attribute had to attribute levels. Orthogonal experimental design was used to create 8 different models, whilst avoiding correlation between the different combinations. The attributes were varied in the base model of the Eindhoven station area redevelopment by CoHeSIVE (2022b). Unity was used to create the virtual environment. A participant ID script, position logger, rotation logger and eye-collider interaction script were added to the model to log the behaviours. As ultimately the built-in eye-tracker of the HTC Vive Pro Eye headset did not work.

A total of 32 participants participated in the experiments, which incorporated a visit to three of the eight models, and answering multiple choice, open, and interview questions on their experiences and behaviour. The Unity model created logfiles for the position and eye-interaction analyses. The interview questions, along with the open questions were analysed using an open, descriptive coding method. One of the most important findings was that the presence of greenery did improve the user-experience to some extent. However, the amount of greenery should not be too much, as it becomes overwhelming and should not interfere with the walking path. The addition of fountains was generally seen as fun, but also for this attribute applied that the placement should not interfere with the walking path.

In the models with skyscrapers, the participants tended to feel "pushed out" and preferred to spend their time in the more open areas in the model. This was explained in the open questions and could be seen in the heatmaps of the position analysis as well. The eye-data was visualised using spikes to indicate the rotation of the HMD and analysed using count tables of the number of times an interaction with a collider object occurred. There were especially a lot of interactions with trees and the façades in the model. The scan path between the two was also the most observed sequence.

However, as the eye-data gathered in this method is not as detailed as it could have been, when using a built-in eye-tracker in the HMD, it was rather inconclusive. The rotation visualisations were 3D plots, but when visualised on a 2D image, it is still hard to derive information from it. In the case the built-in eye-tracker would have worked, it would have projected the gaze of the participants as a spot in a 3D visualisation, rather than the suggestion of rotation that has been analysed in this study. The spread of these gaze points in a 3D plot could be projected over the 3D environment and possibly give a clearer picture of the gaze points, so it would become easier to derive conclusions from the dataset. Next to that, the accuracy of the dataset would improve, and it would be easier to derive fixations and gaze sequences. In this study the HTC Vive Pro Eye HMD was used. It does not have a preset eye-tracking function for the built-in eye-tracker. However, HTC has created a software development kit: SRanipal SDK, which has functions that could be incorporated into C# scripts in Unity, to gather the required dataset from the VR experiment. Ugwitz et al. (2022) suggested a cone-model for the eye-tracking, as the eye-tracker generally does not consider semi-transparent objects and converging eye-sight. The traditional eye-tracker suggests that when people look at trees, they only see the tree, however, often they might also see the object behind the tree through the foliage. By computing multiple gaze rays in a cone shape, not only the object straight looked at is logged, but also the objects in close surrounding. Providing more accurate data on the actual view of the person.

To answer the main research question, several regression analyses were conducted. First three regression analyses were run, separating the user-experience in order they were visited. In the regression model for the first visited models, it turned out that 52.7% of the variation could be explained by the regression model and the type of façade and the presence of water were significant. In this model it could be concluded that blank façades and the presence of fountains increases the user-experience. However, in the other regression models, none of the attributes turned out to be statistically significant. A fixed effects panel regression was conducted to account for variation in between an individual. Also, this model did not have any statistically significant variables.

Nonetheless, there are also some limitations to such experiments. The view in the HMD is limited compared to the view in the real world, therefore, the participants had to rotate their head more, instead of just looking up, as they would have done in the real world. Next to that, the movements made do not translate completely to the movements in VR, creating a sort of distortion and/or delay in the view. By optimizing the design and the file that is run, the delays might decrease. In this study, the placement of the varied attributes was rather randomly chosen. This led to participants commenting on the placement of for example the grass and the fountains, which limited the walkability of the model. This could have an unintended effect on the user-experience, as the positive effect of these attributes, might be overshadowed by the limited walkability of the model, due to the placement.

For future research it is really advised to put more attention to the design of the virtual environments. In this study the models were created in SketchUp and the collider and VR objects were added in Unity. All models were created in the same file, as separate scenes. This could have made the program unnecessary large to run. Additionally, Unity has the option to create prefabricated objects, so, for example, only one tree has to be created with all the preferred properties, then the prefabricated objects can be saved and the trees can be placed in the model wherever necessary. Additionally, adding the materials in Unity rather than in SketchUp makes it easier for Unity to render, and it is immediately visible how the material will render in play mode.

In this research 32 participants were recruited on the University campus, which is only a limited number of participants. With a larger number of participants, it might be possible to get statistically significant results from the regression analysis, or to apply different types of statistical testing. Some personal characteristics were questioned, but what was not considered is neurodivergence. Neurodivergent brains tend to process stimuli differently than neurotypical brains. This could create a difference in behaviour and user-experience and could be accounted for in future research .

In general, it can be concluded that immersive virtual reality with eye-tracking possibilities is a promising tool to analyse and quantify user-experience. The answers given to the open and interview questions did correspond to the position analysis to some extent. The eye-tracking data could add more in-depth insights in how the participants process their environment and experiences. Remarks on the VR experiment were that the participants liked to be fully immersed in the environment, that the experiments had an explorative character with freedom of movement. Overall, they found it a fun experience and some indicated that the equipment was straightforward in use.

Based on the answers to the open questions and the behaviour showed in the position analysis, it could be concluded that the design of high-rise urban areas does affect its user. Urban designers should take that into account and design such areas with attention to the context. Areas with high-rise buildings rather than skyscrapers, a presence of areas for relaxation, and recreational greenery are favoured by the visitors and will contribute positively to their user-experience.

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# Appendices

## Appendix A. Unity Scripts

A. Participant ID

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class ParticipantID : MonoBehaviour
{
   // Assigning a model and participant number in the unity editor
   public int modelNumber;
   public int participantNumber;
}
```

B. Position Logger

```
using System.Collections;
using System.IO;
using UnityEngine;

public class PositionLogger : MonoBehaviour
{
   public Transform participant; // Reference to the participant object
   private int modelNumber;
   private int participantNumber;

   private string logFileName; // Name of the log file

   private float logInterval = 0.5f; // Log position every 0.5 seconds
   private float timer;

   private void Start()
   {
      // Get the modelNumber and participantNumber from the Participant
      ParticipantID Participant = FindObjectOfType<ParticipantID>();
      modelNumber = Participant.modelNumber;
      participantNumber = Participant.participantNumber;

      string logPath = Application.dataPath + "/logs/";
      if (!Directory.Exists(logPath))
      {
         Directory.CreateDirectory(logPath);
      }

      logFileName = $"M{modelNumber}_P{participantNumber}_Positions.csv";
      string filePath = logPath + logFileName;

      if (!CheckExistingLogFile(filePath))
      {
         File.WriteAllText(filePath,
"Time,PositionX,PositionY,PositionZ,RotationX,RotationY,RotationZ\n");
      }
   }

   private bool CheckExistingLogFile(string filePath)
   {
      if (File.Exists(filePath))
      {
         Debug.LogWarning("Log file already exists. Appending to existing file.");
         return true;
      }
```

```
        return false;
    }

    private void Update()
    {
        timer += Time.deltaTime;

        if (timer >= logInterval)
        {
            LogPosition();
            timer = 0;
        }
    }

    public void LogPosition()
    {
        Vector3 position = participant.position;
        Vector3 rotation = participant.eulerAngles;

        string log =
$"{Time.time},{position.x},{position.y},{position.z},{rotation.x},{rotation.y},{rotation.z},\n";

        string filePath = Application.dataPath + $"/logs/{logFileName}";
        File.AppendAllText(filePath, log);
    }

    public void LogInteraction()
    {
        Vector3 position = participant.position;
        Vector3 rotation = participant.eulerAngles;

        string log =
$"{Time.time},{position.x},{position.y},{position.z},{rotation.x},{rotation.y},{rotation.z},PickU
p\n";

        string filePath = Application.dataPath + $"/logs/{logFileName}";
        File.AppendAllText(filePath, log);
    }
}
```

C. Eye-Collider Logger

```
using UnityEngine;
using System.IO;
using System.Text;

public class AttributeLogger : MonoBehaviour
{
    public Transform participant; // Reference to the participant object
    private int modelNumber;
    private int participantNumber;

    private string logFileName; // Name of the log file

    private void Start()
    {
        // Get the modelNumber and participantNumber from the Participant
        ParticipantID Participant = FindObjectOfType<ParticipantID>();
        modelNumber = Participant.modelNumber;
        participantNumber = Participant.participantNumber;

        // Create log file if it doesn't exist
        string logPath = Application.dataPath + "/logs/";
        if (!Directory.Exists(logPath))
        {
            Directory.CreateDirectory(logPath);
        }

        logFileName = $"M{modelNumber}_P{participantNumber}_Interactions.csv";
        string filePath = logPath + logFileName;

        if (!CheckExistingLogFile(filePath))
        {
            File.WriteAllText(filePath, "Time,interactionType\n");
        }
    }

    private bool CheckExistingLogFile(string filePath)
    {
        if (File.Exists(filePath))
        {
            Debug.LogWarning("Log file already exists. Appending to existing file.");
            return true;
        }
        return false;
    }
```

```
    void OnTriggerEnter(Collider other)
    {
        if (gameObject.CompareTag("Cylinder"))
        {
            string interactionType = other.gameObject.tag;

            // Check the tag of the collided object and set interactionType accordingly
            if (other.gameObject.CompareTag("Tree"))
            {
                interactionType = "Tree";
            }
            else if (other.gameObject.CompareTag("Grass"))
            {
                interactionType = "Grass";
            }
            else if (other.gameObject.CompareTag("Water"))
            {
                interactionType = "Water";
            }
            else if (other.gameObject.CompareTag("Facade"))
            {
                interactionType = "Facade";
            }
            else if (other.gameObject.CompareTag("Height"))
            {
                interactionType = "Height";
            }

            {
                string log = $"{Time.time},{interactionType}\n";

                string filePath = Application.dataPath + $"/logs/{logFileName}";
                File.AppendAllText(filePath, log);
            }
        }
    }

    // Method to log interactions
    public void LogInteraction(string interactionType)
    {
        string log = $"{Time.time},{interactionType}\n";

        string filePath = Application.dataPath + $"/logs/{logFileName}";
        File.AppendAllText(filePath, log);
    }

}
```

D. Eye-Tracker Logger

```
using System;
using System.IO;
using UnityEngine;
using ViveSR.anipal.Eye;
using System.Collections;
using System.Runtime.InteropServices;
using ViveSR.anipal;
using ViveSR;

public class EyetrackingLogger : MonoBehaviour
{
   public Transform participant; // Reference to the participant object
   private int modelNumber;
   private int participantNumber;

   private static string logFileName; // Name of the log file

   private static EyeData_v2 eyeData = new EyeData_v2();
   public EyeParameter eye_parameter = new EyeParameter();
   public GazeRayParameter gaze = new GazeRayParameter();
   private static bool eye_callback_registered = false;

   private static long MeasureTime;
   private static float time_stamp;
   private static int frame;
   private const int maxframe_count = 120 * 6000;              // Maximum number of samples
for eye-tracking (120 Hz * time in seconds). Changed to 10 minutes, check this in the pilot
test!

   private static UInt64 eye_valid_L, eye_valid_R;              // The bits explaining the validity
of eye data.
   private static float openness_L, openness_R;                 // The level of eye openness.
   private static float pupil_diameter_L, pupil_diameter_R;       // Diameter of pupil dilation.
   private static Vector2 pos_sensor_L, pos_sensor_R;             // Positions of pupils.
   private static Vector3 gaze_origin_L, gaze_origin_R;           // Position of gaze origin.
   private static Vector3 gaze_direct_L, gaze_direct_R;           // Direction of gaze ray.
   private static float frown_L, frown_R;                         // The level of user's frown.
   private static float squeeze_L, squeeze_R;                     // The level to show how the eye is
closed tightly.
   private static float wide_L, wide_R;                           // The level to show how the eye is
open widely.
   private static double gaze_sensitive;                          // The sensitive factor of gaze ray.
   private static float distance_C;                               // Distance from the central point of right
and left eyes.
```

```
    private static bool distance_valid_C;                       // Validity of combined data of right
and left eyes.
    public bool cal_need;                                        // Calibration judge.
    public bool result_cal;                                      // Result of calibration.
    private static int track_imp_cnt = 0;
    private static TrackingImprovement[] track_imp_item;
    private static EyetrackingLogger instance;

    void Start()
    {
        instance = this;
        Invoke("SystemCheck", 0.5f);              // System check.
        SRanipal_Eye_v2.LaunchEyeCalibration();     // Perform calibration for eye-tracking.
        Calibration();
        Invoke("Measurement", 0.5f);              // Start the measurement of ocular movements
in a separate callback function.

        ParticipantID Participant = FindObjectOfType<ParticipantID>();
        modelNumber = Participant.modelNumber;
        participantNumber = Participant.participantNumber;

        string logPath = Application.dataPath + "/logs/";
        if (!Directory.Exists(logPath))
        {
            Directory.CreateDirectory(logPath);
        }

        logFileName = $"M{modelNumber}_P{participantNumber}_EyeData.csv";
        string filePath = Path.Combine(logPath, logFileName);

        InvokeRepeating("RecordEyeData", 0f, 0.008333f); // Invoke every frame (assuming 120
Hz)

    }

    void SystemCheck()
    {
        if (SRanipal_Eye_API.GetEyeData_v2(ref eyeData) == ViveSR.Error.WORK)
        {
            Debug.Log("Device is working properly.");
        }

        if (SRanipal_Eye_API.GetEyeParameter(ref eye_parameter) == ViveSR.Error.WORK)
        {
            Debug.Log("Eye parameters are measured.");
        }
```

```
        //  Check again if the initialisation of eye-tracking functions successfully. If not, we stop
playing Unity.
        Error result_eye_init = SRanipal_API.Initial(SRanipal_Eye_v2.ANIPAL_TYPE_EYE_V2,
IntPtr.Zero);

        if (result_eye_init == Error.WORK)
        {
            Debug.Log("[SRanipal] Initial Eye v2: " + result_eye_init);
        }
    }

    void Calibration()
    {
        SRanipal_Eye_API.IsUserNeedCalibration(ref cal_need);          // Check the calibration
status. If needed, we perform the calibration.

        if (cal_need == true)
        {
            result_cal = SRanipal_Eye_v2.LaunchEyeCalibration();

            if (result_cal == true)
            {
                Debug.Log("Calibration is done successfully.");
            }
        }

        if (cal_need == false)
        {
            Debug.Log("Calibration is not necessary");
        }
    }

    void Measurement()
    {
        EyeParameter eye_parameter = new EyeParameter();
        SRanipal_Eye_API.GetEyeParameter(ref eye_parameter);

        if (SRanipal_Eye_Framework.Instance.EnableEyeDataCallback == true &&
eye_callback_registered == false)
        {

SRanipal_Eye_v2.WrapperRegisterEyeDataCallback(Marshal.GetFunctionPointerForDelegate
((SRanipal_Eye_v2.CallbackBasic)EyeCallback));
            eye_callback_registered = true;
        }
```

```
        else if (SRanipal_Eye_Framework.Instance.EnableEyeDataCallback == false &&
eye_callback_registered == true)
        {

SRanipal_Eye_v2.WrapperUnRegisterEyeDataCallback(Marshal.GetFunctionPointerForDeleg
ate((SRanipal_Eye_v2.CallbackBasic)EyeCallback));
            eye_callback_registered = false;
        }
    }



    private static void EyeCallback(ref EyeData_v2 eye_data)
    {
        EyeParameter eye_parameter = new EyeParameter();
        SRanipal_Eye_API.GetEyeParameter(ref eye_parameter);
        eyeData = eye_data;

        SRanipal_Eye_API.GetEyeData_v2(ref eyeData);

        MeasureTime = DateTime.Now.Ticks;
        time_stamp = eyeData.timestamp;
        frame = eyeData.frame_sequence;
        eye_valid_L = eyeData.verbose_data.left.eye_data_validata_bit_mask;
        eye_valid_R = eyeData.verbose_data.right.eye_data_validata_bit_mask;
        openness_L = eyeData.verbose_data.left.eye_openness;
        openness_R = eyeData.verbose_data.right.eye_openness;
        pupil_diameter_L = eyeData.verbose_data.left.pupil_diameter_mm;
        pupil_diameter_R = eyeData.verbose_data.right.pupil_diameter_mm;
        pos_sensor_L = eyeData.verbose_data.left.pupil_position_in_sensor_area;
        pos_sensor_R = eyeData.verbose_data.right.pupil_position_in_sensor_area;
        gaze_origin_L = eyeData.verbose_data.left.gaze_origin_mm;
        gaze_origin_R = eyeData.verbose_data.right.gaze_origin_mm;
        gaze_direct_L = eyeData.verbose_data.left.gaze_direction_normalized;
        gaze_direct_R = eyeData.verbose_data.right.gaze_direction_normalized;
        gaze_sensitive = eye_parameter.gaze_ray_parameter.sensitive_factor;
        frown_L = eyeData.expression_data.left.eye_frown;
        frown_R = eyeData.expression_data.right.eye_frown;
        squeeze_L = eyeData.expression_data.left.eye_squeeze;
        squeeze_R = eyeData.expression_data.right.eye_squeeze;
        wide_L = eyeData.expression_data.left.eye_wide;
        wide_R = eyeData.expression_data.right.eye_wide;
        distance_valid_C = eyeData.verbose_data.combined.convergence_distance_validity;
        distance_C = eyeData.verbose_data.combined.convergence_distance_mm;
        track_imp_cnt = eyeData.verbose_data.tracking_improvements.count;
```

```
        string dataLine = $"{MeasureTime},{time_stamp},{frame},{eye_valid_L},{eye_valid_R},"
+
          $"{openness_L},{openness_R},{pupil_diameter_L},{pupil_diameter_R}," +
          $"{pos_sensor_L.x},{pos_sensor_L.y},{pos_sensor_R.x},{pos_sensor_R.y}," +

$"{gaze_origin_L.x},{gaze_origin_L.y},{gaze_origin_L.z},{gaze_origin_R.x},{gaze_origin_R.y},{g
aze_origin_R.z}," +

$"{gaze_direct_L.x},{gaze_direct_L.y},{gaze_direct_L.z},{gaze_direct_R.x},{gaze_direct_R.y},{
gaze_direct_R.z}," +
          $"{gaze_sensitive},{frown_L},{frown_R},{squeeze_L},{squeeze_R},{wide_L},{wide_R},"
+
          $"{(distance_valid_C ? 1 : 0)},{distance_C},{track_imp_cnt}\n";

        RaycastHit hit;
        Ray gazeRay = new Ray(gaze_origin_L, gaze_direct_L);
        if (Physics.Raycast(gazeRay, out hit, Mathf.Infinity))
        {
          if (instance != null)
          {
            instance.LogInteraction(hit.collider.gameObject);
          }
        }

        string filePath = Application.dataPath + $"/logs/{logFileName}";
        File.AppendAllText(filePath, dataLine);

    }

    private void LogInteraction(GameObject interactedObject)
    {
        Vector3 position = participant.position;
        string log =
$"{Time.time},{position.x},{position.y},{position.z},{interactedObject.name}\n";

        string filePath = Application.dataPath + $"/logs/{logFileName}";
        File.AppendAllText(filePath, log);

        Debug.Log($"Interaction logged with {interactedObject.name}");
    }
}
```

**Appendix B. Description of the Experiment**

*The purpose of this research project is to study user-experience in high-rise environments using virtual reality and eye-tracking technologies.*

---

Dear Sir/Madam,

You have been invited to take part in research project Measuring the User-Experience in High-Rise Urban Areas Using Virtual Reality and Eye-Tracking Technologies, because you applied to participate in this study through social media, personal network or responding to message by the study association.

Participation in this research project is voluntary: the decision to take part is up to you. Before you decide to participate we would like to ask you to read the following information, so that you know what the research project is about, what we expect from you and how we deal with processing your personal data. Based on this information you can indicate via the consent declaration whether you consent to take part in this research project and the processing of your personal data.

You may of course always contact the researcher via r.d.limburg@student.tue.nl if you have any questions, or you can discuss this information with people you know.

There are 18 questions in this survey. This survey is anonymous.

The record of your survey responses does not contain any identifying information about you unless a specific survey question explicitly asked for it.

If you used an identifying token to access this survey, please rest assured that this token will not be stored together with your responses. It is managed in a separate database and will only be updated to indicate whether you did (or did not) complete this survey. There is no way of matching identification tokens with survey responses.

- ☐ I consent to processing my personal data gathered during the research in the way described in the information sheet.

Additional Informed Consent Questions

Furthermore, I consent to the following parts of the research project:

1. I am sufficiently informed about the research project through a separate information sheet. I have read the information sheet and have had the opportunity to ask questions. These questions have been answered satisfactorily.
   - ☐ Yes
   - ☐ No

2. I take part in this research project voluntarily. There is no explicit or implicit pressure for me to take part in this research project. It is clear to me that I can end

participation in this research project at any moment, without giving any reason. I do not have to answer a question if I do not wish to do so.

- ☐ Yes
- ☐ No

Date of agreement: dd.mm.yyyy

## Personal Characteristics

The first part of the questionnaire will focus on some personal characteristics.

1. What is your gender?
   - ☐ Male
   - ☐ Female

2. What is your age?
   - ☐ 18-21
   - ☐ 22-25
   - ☐ 26+

3. What term describes the urbanisation level of your living environment best?
   - ☐ Urban
   - ☐ Suburban
   - ☐ Rural

4. How frequent do you visit high-rise environments?
   - ☐ Rarely
   - ☐ Less than 4 times a year
   - ☐ Approximately 6 times a year
   - ☐ Approximately once a month
   - ☐ Once a week or more often

5. To what extent do the following statements describe your personality?

| | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| I am arousal seeking | Strongly Disagree | Disagree | Neither agree nor disagree | Agree | Strongly Agree |
| I am extrovert | Strongly Disagree | Disagree | Neither agree nor disagree | Agree | Strongly Agree |
| I have tendency towards negative feelings | Strongly Disagree | Disagree | Neither agree nor disagree | Agree | Strongly Agree |

6. To what extent do the following statements describe your current mood?

| | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| How safe do you feel right now? | Very Unsafe | Unsafe | Neither unsafe nor safe | Safe | Very Safe |
| How comfortable do you feel right now? | Very Uncomfortable | Uncomfortable | Neither uncomfortable nor comfortable | Comfortable | Very Comfortable |
| How annoyed do you feel right now? | Very Pleased | Pleased | Neither pleased nor annoyed | Annoyed | Very Annoyed |
| How happy do you feel right now? | Very Unhappy | Unhappy | Neither unhappy nor happy | Happy | Very Happy |

7. Are you familiar with using a head-mounted display (HMD) in Immersive VR?
- ☐ Yes, I use one regularly
- ☐ Yes, I have used one before
- ☐ No, I have never used one before

8. Are you familiar with the redevelopment plans of the Eindhoven Station area, otherwise known as District E?
- ☐ Yes, I am familiar with the redevelopment project.
- ☐ Yes, I have seen some announcements.
- ☐ No, I was not aware of the redevelopment plan.

9. If you are familiar with the redevelopment plan, do you have an opinion about it?
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
________________________________________________________________

User-experience

The second part of the questionnaire will ask questions about the models you are about to visit. In total you will visit 3 different models. After visiting one model, some questions about the experience of the environment will be asked.

1. You are about to enter the first model. Would you like to try out the head-mounted display (HMD) and commands first in a blank model?
   - ☐ Yes
   - ☐ No

It is time to put on the head-mounted display (HMD). Once you have put on the head-mounted display (HMD) and have finished the calibration, you will find yourself in front of Eindhoven Central Station. Immerge yourself in the situation that you are at the station to pick up a friend, however, their train is delayed, so you have some time to kill. You have decided to go outside and walk around for a bit, whilst waiting for them to arrive. Once you have exited the station building, you look to the left and see the student hub and a new developed building. Right in front of the station building, there is a square and to the right, towards the city centre, three towers are built. You will walk towards the three towers, which have a smaller square in the middle.

The experiment is about experiencing the area, so really try to focus on strolling along the path, looking around, taking in the environment. You can walk around within the limits of this room and use the controllers to transport over larger distances. Once you feel you have a good understanding of the model and are finished, or if you start to experience cybersickness, please let me know and you are free to leave the model whenever.

The following questions are about the first model you have visited.

1. Please select for each of the following statements the one that describes your experience in the model best. Walking around the area…

| | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| I feel… | Very Unsafe | Unsafe | Neither unsafe nor safe | Safe | Very Safe |
| I feel… | Very Uncomfortable | Uncomfortable | Neither uncomfortable nor comfortable | Comfortable | Very Comfortable |
| I feel… | Very Pleased | Pleased | Neither pleased nor annoyed | Annoyed | Very Annoyed |
| I feel… | Very Unhappy | Unhappy | Neither unhappy nor happy | Happy | Very Happy |

2. Could you explain what made you feel …?
   - (Un-)safe

     ______________________________________________________________
     ______________________________________________________________
     ____________
   - (Un-)comfortable

     ______________________________________________________________
     ______________________________________________________________
     ____________
   - Annoyed or pleased

______________________________________________________________________
______________________________________________________________________
_____________

- (Un-)happy
______________________________________________________________________
______________________________________________________________________
_____________

3. Would you like to visit this area more often? Why (not)?
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

Thank you for answering.

If you are ready, it is time to visit the second model. Please clear your mind from the last experience and reimagine the scene: you are at the station to pick up a friend, however, their train is delayed, so you have some time to kill. You have decided to go outside and walk around for a bit, whilst waiting for them to arrive. Once you have exited the station building, you look to the left and see the student hub and a new developed building. Right in front of the station building, there is a square and to the right, towards the city centre, three towers are built. You will walk towards the three towers, which have a smaller square in the middle.

Once again, the experiment is about experiencing the area, so really try to focus on strolling along the path, looking around, taking in the environment. You can walk around within the limits of this room and use the controllers to transport over larger distances. Once you feel you have a good understanding of the model and are finished, or if you start to experience cybersickness, please let me know and you are free to leave the model whenever.

The following questions are about the second model you have visited.

4. Please select for each of the following statements the one that describes your experience in the model best. Walking around the area…

| | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|
| I feel… | Very Unsafe | Unsafe | Neither unsafe nor safe | Safe | Very Safe |
| I feel… | Very Uncomfortable | Uncomfortable | Neither uncomfortable nor comfortable | Comfortable | Very Comfortable |
| I feel… | Very Pleased | Pleased | Neither pleased nor annoyed | Annoyed | Very Annoyed |
| I feel… | Very Unhappy | Unhappy | Neither unhappy nor happy | Happy | Very Happy |

5. Could you explain what made you feel …?

- (Un-)safe
______________________________________________________________________
______________________________________________________________________
_____________
- (Un-)comfortable
______________________________________________________________________
______________________________________________________________________
_____________
- Annoyed or pleased.
______________________________________________________________________
______________________________________________________________________
_____________
- (Un-)happy
______________________________________________________________________
______________________________________________________________________
_____________

6. Would you like to visit this area more often? Why (not)?
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

Thank you for answering.

If you are ready, it is time to visit the third and final model. Please clear your mind from the previous experiences and reimagine the scene: you are at the station to pick up a friend, however, their train is delayed, so you have some time to kill. You have decided to go outside and walk around for a bit, whilst waiting for them to arrive. Once you have exited the station building, you look to the left and see the student hub and a new developed building. Right in front of the station building, there is a square and to the right, towards the city centre, three towers are built. You will walk towards the three towers, which have a smaller square in the middle.

Once again, the experiment is about experiencing the area, so really try to focus on strolling along the path, looking around, taking in the environment. You can walk around within the limits of this room and use the controllers to transport over larger distances. Once you feel you have a good understanding of the model and are finished, or if you start to experience cybersickness, please let me know and you are free to leave the model whenever.

The following questions are about the third and final model you have visited.

7. Please select for each of the following statements the one that describes your experience in the model best. Walking around the area…

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| I feel… | Very Unsafe | Unsafe | Neither unsafe nor safe | Safe | Very Safe |
| I feel… | Very Uncomfortable | Uncomfortable | Neither uncomfortable nor comfortable | Comfortable | Very Comfortable |
| I feel… | Very Pleased | Pleased | Neither pleased nor annoyed | Annoyed | Very Annoyed |
| I feel… | Very Unhappy | Unhappy | Neither unhappy nor happy | Happy | Very Happy |

8. Could you explain what made you feel …?
   - (Un-)safe
     ______________________________________________________________________
     ______________________________________________________________________
     _____________
   - (Un-)comfortable
     ______________________________________________________________________
     ______________________________________________________________________
     _____________
   - Annoyed or pleased
     ______________________________________________________________________
     ______________________________________________________________________
     _____________
   - (Un-)happy
     ______________________________________________________________________
     ______________________________________________________________________
     _____________

9. Would you like to visit this area more often? Why (not)?
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   _____________________________________________________________________

Thank you! Now you have finished visiting the different models and the questions per model.

## Additional Questions

To finalise the experiment, I would like to ask some questions regarding your experiences during the experiment and your opinion of the redevelopment. Please answer them according to your experiences and opinions.

Firstly, some questions about the experiment in VR.

1. Did you experience any symptoms of cybersickness? If multiple answers apply, please indicate:
   - ☐ No, I did not experience any symptoms.
   - ☐ Yes, I experienced the following symptoms:

- Nausea
- Disorientation
- Headache
- Tiredness
- Other, namely: ________________________________________________
  ________________________________________________
  ________________________________________________
  ______________________

2. Could you elaborate on your experience in VR and with the head-mounted display (HMD)?

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   _______________________________________________________________

Secondly, some questions about your opinion on the redevelopment plans and different models.

3. After visiting different configurations of the model, did you form an opinion about the redevelopment plans? Could you please elaborate? And if you were already familiar with the plans, did the VR experience change your opinion in some way?

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   _______________________________________________________________

4. If you could improve the area, what changes would you like to suggest?

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________
   _______________________________________________________________

5. What is your opinion about the height of the buildings? Did it influence how you experienced the environment? (e.g., Do you prefer a certain height, why (not)?)

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

6. What is your opinion about the variation in height of the buildings? Did it influence how you experienced the environment? (e.g., Do you prefer variation or all the same height, why (not)?)

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

7. What is your opinion about the façade of the buildings? Did it influence how you experienced the environment? (e.g., Do you prefer a blank façade or a mirrored or active façade, why (not)?)

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

8. What is your opinion about the models where grass was added? Did it influence how you experienced the environment?

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
_____________________________________________________________________

9. What is your opinion about trees in the area? Did it influence how you experienced the environment? (e.g., Do you prefer many or fewer trees, rather have them spread or Clustering, why?)

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

____________________________________________________________________
___________________________________________________________________

10. What is your opinion about water fountains in the area? Did it influence how you experienced the environment? (e.g., Do you prefer having them in the area or not, why?)

____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________
___________________________________________________________________

This is the end of the questionnaire, thank you for participating!

If you have any additional questions or remarks, please add them here or contact the researcher (r.d.limburg@student.tue.nl).

## Appendix C. Informed Consent Form

A. This consent form (incl. privacy declaration) should be used in the following situation:

Within the scope of a research project, you process personal data with consent of the participants as legal basis. There is no special or sensitive (confidential) personal data (see FAQ) and the research project does not require a DPIA (see FAQ). The description of the research project is not very extensive. The privacy statement and the consent form can therefore be joined together.

The information in the side bar is an explanation of the text concerned. These comments must be deleted from the actual document when it is finalized. The text blocks marked in yellow indicate what information should in any case be completed or where the researcher must select an option. Please share this information within this form in the simplest possible phrasing. The template must be followed as strictly as possible and sub-headings may not be deleted.

Based on this information, a potential participant can make an informed and formal decision concerning both participation in the research project and the processing of his/her personal data.

B. integration into web survey

This form can be integrated into an online web survey. This is because consent can also be given through a digital signature or by placing a checkmark.

You can list parts 1-6 on the main page of a website, with the consent form beneath them, and include the remaining parts 7-9 in a separate weblink. Use the text provided for this purpose at the bottom of part 6.

C. Review

Complete the form using track changes and then share it with the data steward of your department for review. You can contact the data steward also for additional support and tailor-made solutions.

**Information sheet for research project “Measuring the User-Experience in High-Rise Urban Areas Using Virtual Reality and Eye-Tracking Observations”**

1. Introduction

You have been invited to take part in research project Measuring the User-Experience in High-Rise Urban Areas Using Virtual Reality and Eye-Tracking Technologies, because you applied to participate in this study through social media, personal network or responding to message by the study association.

Participation in this research project is voluntary: the decision to take part is up to you. Before you decide to participate we would like to ask you to read the following information, so that you know what the research project is about, what we expect from you and how we deal with processing your personal data. Based on this information you can indicate via the consent declaration whether you consent to take part in this research project and the processing of your personal data.

You may of course always contact the researcher via r.d.limburg@student.tue.nl if you have any questions, or you can discuss this information with people you know.

2. Purpose of the research

Romy Limburg will manage this research project.
The purpose of this research project is to study user-experience in high-rise environments using virtual reality and eye-tracking technologies.

3. Controller in the sense of the GDPR

TU/e is responsible for processing your personal data within the scope of the research. The contact details of TU/e are:

Technische Universiteit Eindhoven
De Groene Loper 3
5612 AE Eindhoven

4. What will taking part in the research project involve?

You will be taking part in a research project in which we will gather information by:

- Asking you to fill in a questionnaire during the experiment, this questionnaire will exist of 5 parts. The first part will ask some questions about age, gender, personality, mood, urbanization of living situation and frequency of visits to high-rise environments. The second, third and fourth part will ask 4 questions regarding the experience of visiting the models. The last part will focus on your opinion about the models.
- Interviewing you about your experiences and insights when visiting the model and to record your answers using notes.
- When visiting the models, the head-mounted display (HMD) will track your location, and the researcher will make notes of what you are looking at.

For your participation in this research project, you will not be compensated.

5. Potential risks and inconveniences

Your participation in this research project does not involve any physical, legal, or economic risks. You do not have to answer questions which you do not wish to answer. Your participation is voluntary. This means that you may end your participation at any moment you choose by letting the researcher know this. You do not have to explain why you decided to end your participation in the research project.

During your participation in the VR experiment, you might experience cybersickness or feel unstable. To gain confidence in VR, there will be an optional training round before beginning the experiment. If you do not feel confident you are allowed to stop at any moment. If you are experiencing any symptoms of cybersickness, such as nausea, disorientation, headaches, or tiredness, please stop your participation. You are allowed to stop your participation at any given time and are not obligated to give a reason for it.

6. Withdrawing your consent and contact details

Participation in this research project is entirely voluntary. You may end your participation in the research project at any moment or withdraw your consent to using your data for the research, without specifying any reason. Ending your participation will have no disadvantageous consequences for you.

If you decide to end your participation during the research, the data which you already provided up to the moment of withdrawal of your consent will be used in the research. Do you wish to end the research, or do you have any questions and/or complaints? Then please contact the researcher via r.d.limburg@student.tue.nl.

If you have specific questions about the handling of personal data you can direct these to the data protection officer of TU/e by sending a mail to functionarisgegevensbescherming@tue.nl. Furthermore, you have the right to file a complaint with the Dutch data protection authority: the Autoriteit Persoonsgegevens.

Finally, you have the right to request access, rectification, erasure, or adaptation of your data. Submit your request via privacy@tue.nl.

7. Legal ground for processing your personal data

The legal basis upon which we process your data is consent.

8. What personal data from you do we gather and process?

Within the framework of the research project, we process the following personal data:

| Category | Personal Data |
|---|---|
| *Contact Details* | *Name and Email Address* |
| *Personal Characteristics* | *Gender, Age, Personality (arousal seeking tendencies, extraversion, tendency towards negative feelings)* |
| *Personal Environment* | *Urbanization level of living situation, Frequency of visits to high-rise environments.* |
| *Mood/Experience* | *Safety, Comfort, Happiness, Annoyance* |

Within the framework of the research project your personal data will be shared with:

- *Storage solution: Surfdrive (Netherlands)*
- *Survey tool: LimeSurvey (Germany or Finland)*
- *Device: HTC Vive Pro with Tobii*

9. Confidentiality of data

We will do everything we can to protect your privacy as best as possible. The research results that will be published will not in any way contain confidential information or personal data from or about you through which anyone can recognize you, unless in our consent form you have explicitly given your consent for mentioning your name, for example in a quote.

The personal data that were gathered via on-line surveys, interviews, the eye-tracking tools, and other documents within the framework of this research project, will be stored on Surfdrive for the duration of the study.

The raw and processed research data will be retained until the end of this study and will be immediately after collection be anonymised. After expiration of this time period the data will be either deleted so that it can no longer be connected to an individual person. The research data will, if necessary (e.g., for a check on scientific integrity) and only in anonymous form be made available to persons outside the research group.

This research project was assessed and approved on 3rd of April 2023 by the ethical review committee of Eindhoven University of Technology.

**Consent form for participation by an adult**

By signing this consent form I acknowledge the following:

1. I am sufficiently informed about the research project through a separate information sheet. I have read the information sheet and have had the opportunity to ask questions. These questions have been answered satisfactorily.

2. I take part in this research project voluntarily. There is no explicit or implicit pressure for me to take part in this research project. It is clear to me that I can end participation in this research project at any moment, without giving any reason. I do not have to answer a question if I do not wish to do so.

Furthermore, I consent to the following parts of the research project:

3. I consent to processing my personal data gathered during the research in the way described in the information sheet.

   YES ☐ NO☐

4. I consent to using my answers for quotes in the research publications – without my name being published in these.

   YES ☐ NO☐

Name of Participant:

Signature:

Date:

Name of researcher:

Signature:

Date:

**Appendix D. Thematic analysis of Interview and Open Questions**

*Tabel 1. Overview of Answers to the Interview Questions Per Model – Part 1*

| | M1 | | | M2 | | | M3 | | | M4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** |
| ***Overall building height*** | 6 | Too tall | - | 6 | Too tall | - | 0 | | | 3 | Too tall | - |
| ***Variation of building height*** | 0 | | | 1 | Interesting | + | 0 | | | 0 | | |
| ***Sense of place*** | 3 | Missing | + | 1 | Missing | + | 0 | | | 1 | Missing | + |
| ***Sense of scale*** | 4 | Missing | + | 4 | Missing | + | 0 | | | 3 | Missing | + |
| ***View of the sky*** | 3 | Missing | + | 2 | Missing | + | 0 | | | 0 | | |
| ***Presence of daylight*** | 2 | Missing | + | 2 | Missing | + | 2 | Missing | + | 2 | Missing | + |
| ***Active façade***** | 2 | Open | + | 2 | Blank | - | 0 | | | 1 | Open | + |
| ***Level of architectural detailing*** | 1 | Interesting | + | 1 | Sharp | - | 1 | Interesting | + | 0 | | |
| ***Presence of streetlighting*** | 0 | | | 0 | | | 1 | Pleasant | + | 0 | | |
| ***Amount of grass**** | 0 | | | 2 | Pleasant | + | 1 | Missing | + | 5 | Pleasant | + |
| ***Number of trees**** | 2 | Little | + | 6 | Pleasant | + | 5 | Pleasant | + | 2 | Too many | - |
| ***Clustering of trees**** | 2 | Clustering | + | 0 | | | 0 | | | 0 | | |
| ***Presence of water*** | 0 | | | 6 | Dynamic | + | 1 | Pleasant | + | 6 | Fun | + |

*Tabel 2 Overview of Answers to the Interview Questions Per Model - Part 2*

| | M5 | | | M6 | | | M7 | | | M8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** |
| ***Overall building height*** | 3 | Lower | - | 3 | Too tall | - | 0 | | | 3 | Lower | - |
| ***Variation of building height*** | 0 | | | 0 | | | 0 | | | 3 | Interesting | + |
| ***Sense of place*** | 1 | Present | + | 0 | | | 0 | | | 1 | Missing | + |
| ***Sense of scale*** | 3 | Present | + | 4 | Missing | + | 0 | | | 3 | Missing | + |
| ***View of the sky*** | 0 | | | 0 | | | 0 | | | 0 | | |
| ***Presence of daylight*** | 1 | Present | + | 0 | | | 1 | Missing | + | 2 | Missing | + |
| ***Active façade***** | 1 | Blank | - | 0 | | | 3 | Active | + | 1 | Blank | - |
| ***Level of architectural detailing*** | 4 | Less interesting | + | 0 | | | 0 | | | 1 | Interesting | + |
| ***Presence of streetlighting*** | 1 | Pleasant | + | 1 | Pleasant | + | 0 | | | 0 | | |
| ***Amount of grass**** | 3 | Missing | + | 0 | | | 5 | Pleasant | + | 4 | Pleasant | + |
| ***Number of trees**** | 7 | Little | + | 7 | Many | + | 6 | Little | - | 5 | Pleasant | + |
| ***Clustering of trees**** | 1 | Clustering | + | 0 | | | 1 | Clustering | + | 1 | Organised | + |
| ***Presence of water*** | 6 | Fun | + | 0 | | | 0 | | | 0 | | |

*Tabel 3. Answers to the Open Question Given on Safety, for the first, second and third model.*

| **Safe** | **FIRST VISIT** | | | **SECOND VISIT** | | | **THIRD VISIT** | | | **Total** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Effect** |
| ***Overall building height*** | 2 | Too tall | - | 3 | Too tall | - | 4 | Too tall | - | 9 | - |
| ***Variation of building height*** | 0 | | | 0 | | | | | | 0 | |
| ***Sense of place*** | 7 | Open | + | 0 | | | 2 | Missing | + | 9 | + |
| ***Sense of scale*** | 0 | | | 3 | Missing | + | 2 | Missing | + | 5 | + |
| ***View of the sky*** | 1 | Present | + | 0 | | | 2 | Missing | + | 3 | + |
| ***Presence of daylight*** | 7 | 4 Missing / 3 Present | + | 2 | Missing | | 4 | Missing | + | 13 | + |
| ***Active façade**** | 1 | Active | + | 2 | Active | + | 5 | 2 Active/ 3 Blank | + | 8 | + |
| ***Level of architectural detailing*** | 0 | | | 0 | | | | | | 0 | |
| ***Presence of streetlighting*** | 0 | | | 1 | Pleasant | + | 3 | Pleasant | + | 4 | + |
| ***Amount of grass**** | 2 | Pleasant | + | 2 | Pleasant | + | 2 | Pleasant | + | 6 | + |
| ***Number of trees**** | 3 | Pleasant | + | 10 | Pleasant | + | 6 | Pleasant | + | 19 | + |
| ***Clustering of trees**** | 0 | | | 0 | | | 1 | Spread | + | 1 | + |
| ***Presence of water*** | 1 | Inviting | + | 2 | Fun | + | 1 | Peaceful | + | 4 | + |

*Tabel 4. Answers to the Open Question Given on Comfort, for the first, second and third model.*

| Comfortable | FIRST VISIT | | | SECOND VISIT | | | THIRD VISIT | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Effect** |
| ***Overall building height*** | 2 | Too tall | - | 1 | Too tall | - | 3 | Too tall | - | 6 | - |
| ***Variation of building height*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Sense of place*** | 2 | Missing | - | 0 | | | 2 | Missing | + | 4 | + |
| ***Sense of scale*** | 8 | Missing | + | 4 | Missing | + | 5 | Missing | + | 17 | + |
| ***View of the sky*** | 0 | | | 1 | Missing | + | 1 | Missing | + | 2 | + |
| ***Presence of daylight*** | 2 | Pleasant | + | 5 | Missing | + | 3 | Missing | + | 10 | + |
| ***Active façade**** | 1 | Blank | - | 1 | Blank | - | 5 | Blank/Active | - | 7 | - |
| ***Level of architectural detailing*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Presence of streetlighting*** | 0 | | | 0 | | | 1 | Pleasant | + | 1 | + |
| ***Amount of grass**** | 2 | Pleasant | + | 4 | Pleasant | + | 3 | Pleasant | + | 9 | + |
| ***Number of trees**** | 5 | Pleasant | + | 11 | Pleasant | + | 11 | Pleasant | + | 27 | + |
| ***Clustering of trees**** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Presence of water*** | 1 | Pleasant | + | 2 | Calm | + | 1 | Inviting | + | 4 | + |

*Tabel 5. Answers to the Open Question Given on Annoyance, for the first, second and third model.*

| Annoyance | FIRST VISIT | | | SECOND VISIT | | | THIRD VISIT | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Effect** |
| ***Overall building height*** | 1 | Too tall | + | 1 | Too tall | + | 2 | Too tall | - | 4 | + |
| ***Variation of building height*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Sense of place*** | 1 | Recognisable | - | 0 | | | 0 | | | 1 | - |
| ***Sense of scale*** | 1 | Missing | - | 1 | Missing | - | 2 | Missing | - | 4 | - |
| ***View of the sky*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Presence of daylight*** | 0 | | | 0 | | | 2 | Missing | - | 2 | - |
| ***Active façade***** | 0 | | | 0 | | | 5 | Blank/Active | - | 5 | - |
| ***Level of architectural detailing*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Presence of streetlighting*** | 0 | | | 0 | | | 0 | | | 0 | |
| ***Amount of grass**** | 3 | Interferes Routing | + | 6 | Interferes Routing | + | 3 | Interferes Routing | + | 12 | + |
| ***Number of trees**** | 6 | Pleasant | - | 11 | Pleasant | - | 13 | Pleasant | - | 30 | - |
| ***Clustering of trees**** | 0 | | | 2 | Spread | + | 1 | Clustering | - | 3 | - |
| ***Presence of water*** | 3 | Fun | - | 5 | Fun | - | 1 | Fun | - | 9 | - |

*Tabel 6. Answers to the Open Question Given on Happiness, for the first, second and third model.*

| Happy | FIRST VISIT | | | SECOND VISIT | | | THIRD VISIT | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Characteristics** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Summary** | **Effect** | **Count** | **Effect** |
| ***Overall building height*** | 0 | | | 1 | Too tall | - | | | | 1 | - |
| ***Variation of building height*** | 0 | | | 0 | | | | | | 0 | + |
| ***Sense of place*** | 2 | Open | + | 0 | | | | | | 2 | + |
| ***Sense of scale*** | 0 | | | 0 | | | | | | 0 | + |
| ***View of the sky*** | 1 | Pleasant | + | 0 | | | | | | 1 | + |
| ***Presence of daylight*** | 0 | | | 1 | Pleasant | + | 2 | Missing | - | 3 | + |
| ***Active façade***** | 1 | Active | + | 0 | | | 1 | Active | + | 2 | + |
| ***Level of architectural detailing*** | 0 | | | 0 | | | | | | 0 | + |
| ***Presence of streetlighting*** | 0 | | | 0 | | | | | | 0 | + |
| ***Amount of grass**** | 2 | Pleasant | + | 1 | Pleasant | + | 4 | Pleasant | + | 7 | + |
| ***Number of trees**** | 5 | Pleasant | + | 9 | Pleasant | + | 10 | Pleasant | + | 24 | + |
| ***Clustering of trees**** | 0 | | | 0 | | | | | | 0 | + |
| ***Presence of water*** | 6 | Fun | + | 8 | Fun | + | 3 | Fun | + | 17 | + |

**Appendix E. MATLAB Script for Position Analysis**

```
% Define the pattern for file names
pattern = 'M2_P*_Positions.csv';

% Get a list of files matching the pattern
files = dir(pattern);

% Initialize arrays to store all X and Y coordinates
allPositionX = [];
allPositionY = [];

% Iterate over each file
for i = 1:length(files)
   % Load position coordinates from CSV
   data = readmatrix(files(i).name);

   % Extract X and Y coordinates
   positionX = data(:, 2); % Second column for X coordinates
   positionY = data(:, 4); % Fourth column for Y coordinates

   % Append the coordinates to the arrays
   allPositionX = [allPositionX; positionX];
   allPositionY = [allPositionY; positionY];
end

% Create a 2D histogram
binWidth = 5; % Adjust bin width as needed
histogram2(allPositionX, allPositionY, 'BinWidth', binWidth, 'DisplayStyle', 'tile');

% Adjust colormap for smoother gradient
colormap('turbo');

xlabel('X Coordinate');
ylabel('Y Coordinate');
title('Heatmap of Model 2 Walking Paths');
```

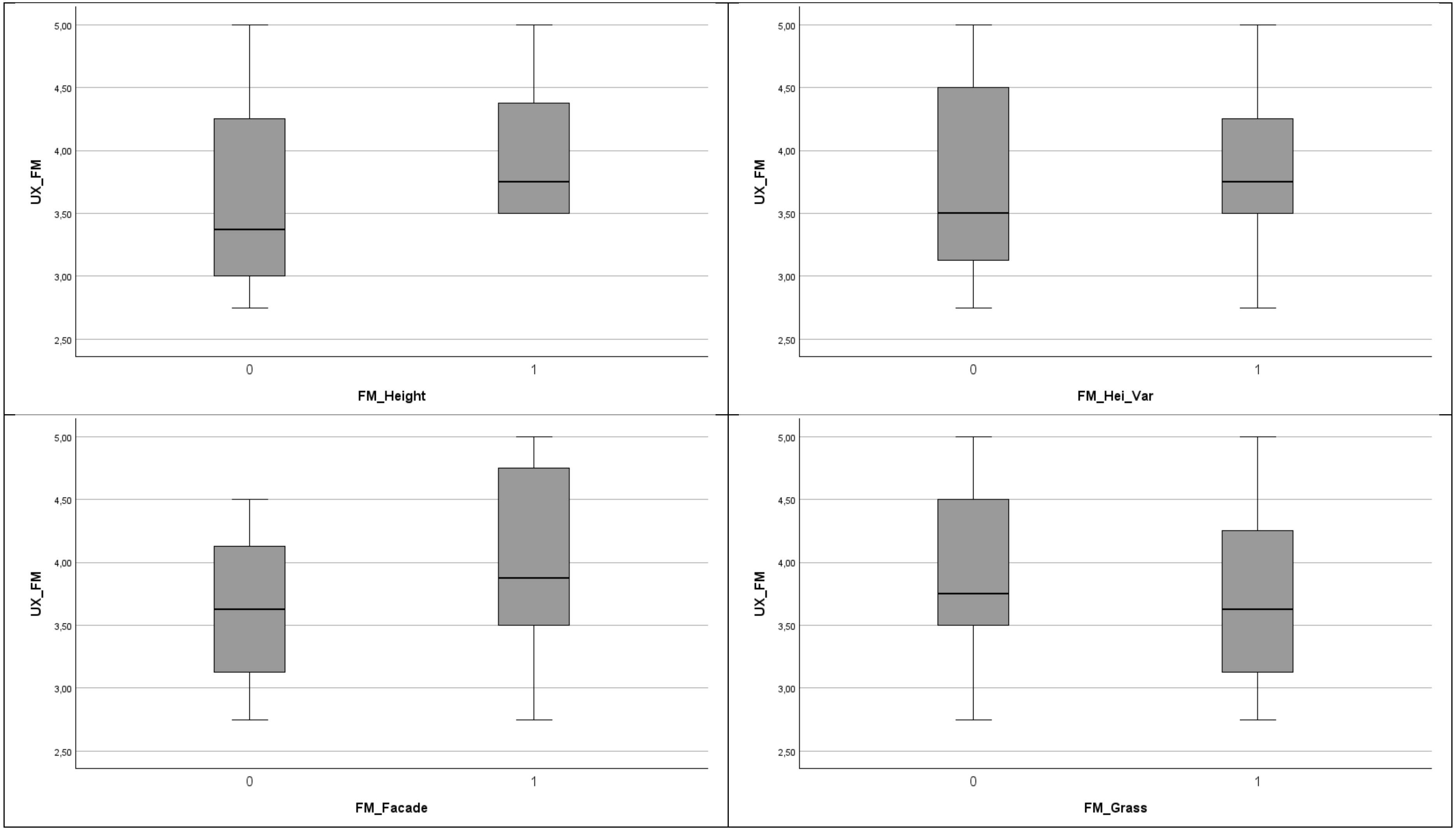
**Appendix F. MATLAB Script for Rotation Analysis**

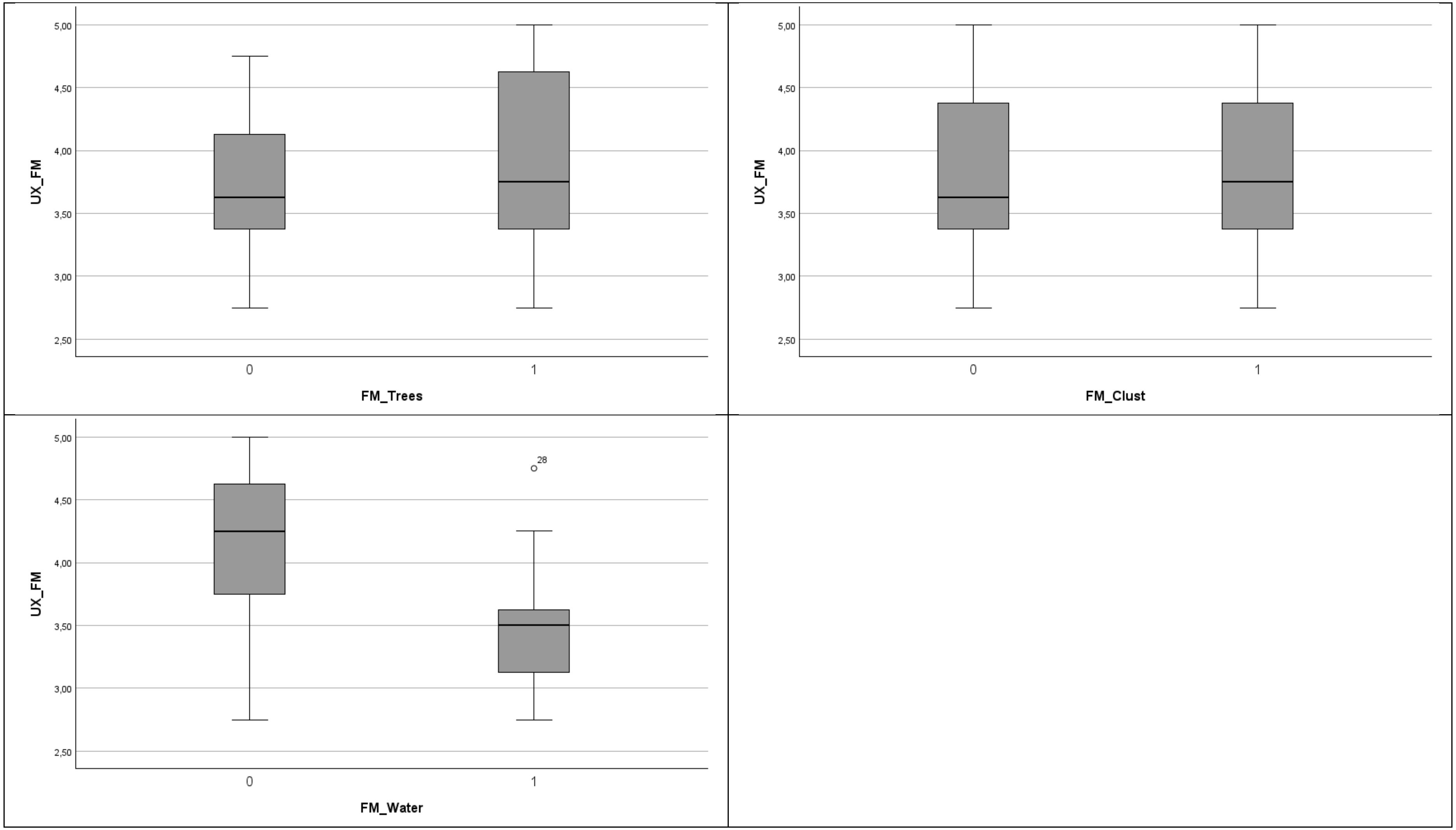
```
% Define the pattern for file names
pattern = 'M1_P*_Positions.csv';

% Get a list of files matching the pattern
files = dir(pattern);

% Preallocate arrays for faster execution
total_points = 0;
for file_index = 1:length(files)
   filename = files(file_index).name;
   data = readmatrix(filename);
   total_points = total_points + size(data, 1);
end

all_x = zeros(total_points, 1);
all_y = zeros(total_points, 1);
all_z = zeros(total_points, 1);
all_rot_x = zeros(total_points, 1);
all_rot_y = zeros(total_points, 1);
all_rot_z = zeros(total_points, 1);

% Accumulate data
start_index = 1;
for file_index = 1:length(files)
   filename = files(file_index).name;
   data = readmatrix(filename);
   num_points = size(data, 1);

   all_x(start_index:start_index+num_points-1) = data(:, 2);
   all_y(start_index:start_index+num_points-1) = data(:, 4);
   all_z(start_index:start_index+num_points-1) = data(:, 3);
   all_rot_x(start_index:start_index+num_points-1) = data(:, 5);
   all_rot_y(start_index:start_index+num_points-1) = data(:, 6);
   all_rot_z(start_index:start_index+num_points-1) = data(:, 7);

   start_index = start_index + num_points;
end

% Create 3D plot
Figure;
scatter3(all_x, all_y, all_z, 10, 'k', 'filled'); % Plot player positions in black and smaller
hold on;

% Define colors based on the rotation angles
rotation_angles = sqrt(all_rot_x.^2 + all_rot_y.^2 + all_rot_z.^2); % Calculate the magnitude
of rotation
```

```
color_map = spring; % Choose 'spring' colormap

% Plot arrows indicating player orientation
scale = 2.5; % Adjust this scale factor based on your preference
for i = 1:numel(all_x)
   direction = [cos(all_rot_y(i))*cos(all_rot_z(i)), ...
            cos(all_rot_x(i))*sin(all_rot_z(i))+sin(all_rot_x(i))*sin(all_rot_y(i))*cos(all_rot_z(i)),
...
            sin(all_rot_x(i))*sin(all_rot_z(i))-cos(all_rot_x(i))*sin(all_rot_y(i))*cos(all_rot_z(i))];
   color_index = ceil(rotation_angles(i) / max(rotation_angles) * size(color_map, 1));
   color = color_map(color_index, :);
   quiver3(all_x(i), all_y(i), all_z(i), direction(1)*scale, direction(2)*scale, direction(3)*scale,
'LineWidth', 1.5, 'Color', color);
end

xlabel('X');
ylabel('Y');
zlabel('Z');
title('Player Position and Orientation Model 1');

grid on;
axis equal; % Equal aspect ratio

% Add colorbar with the same colormap
colormap("spring");
cb = colorbar;
cb.Label.String = 'Rotation Angle';
cb.Label.FontSize = 12;

hold off;
```

## Appendix G. Boxplots analysing outliers using SPSS

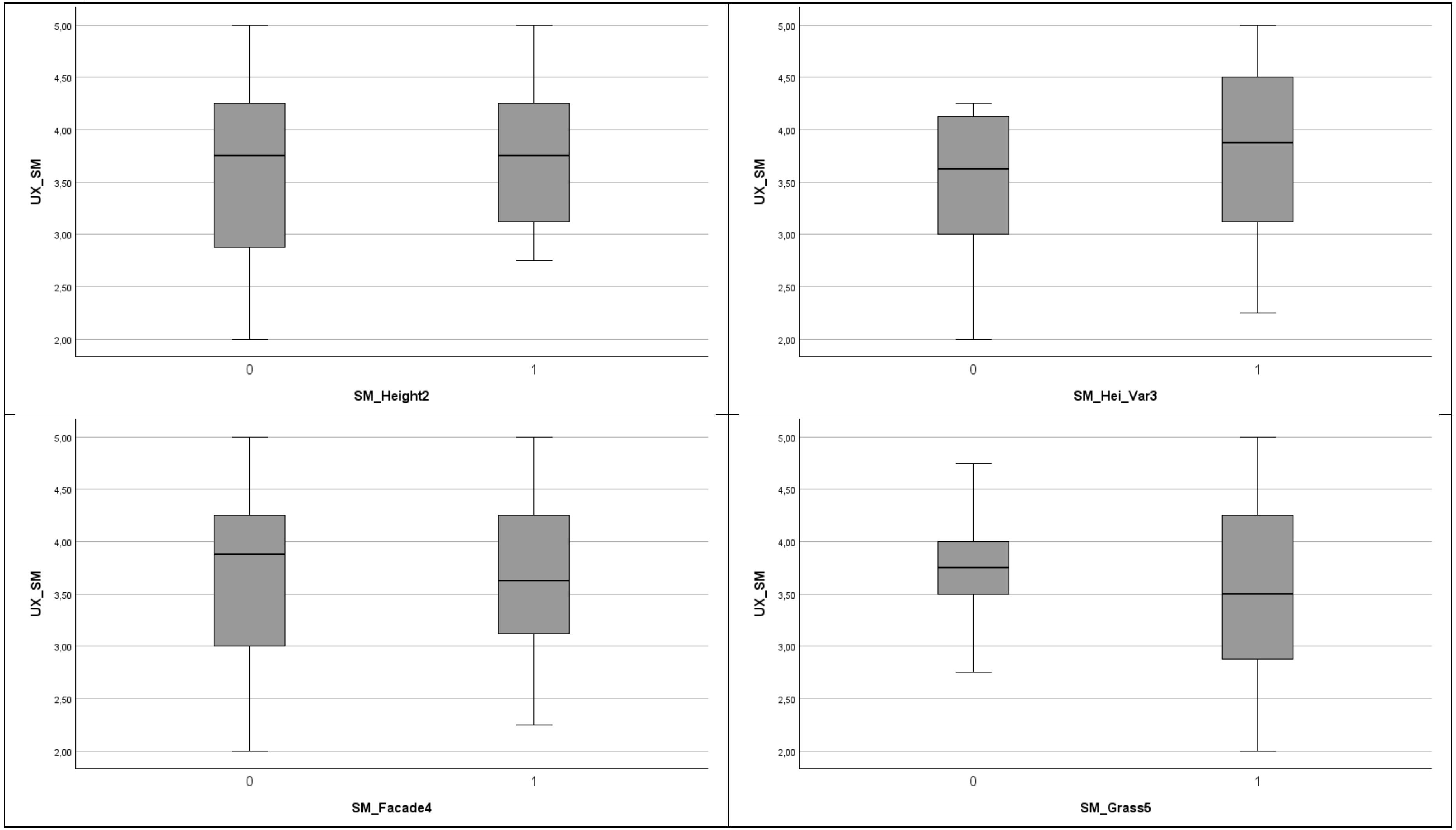
User-experience First Visited Models versus the Environmental Characteristics

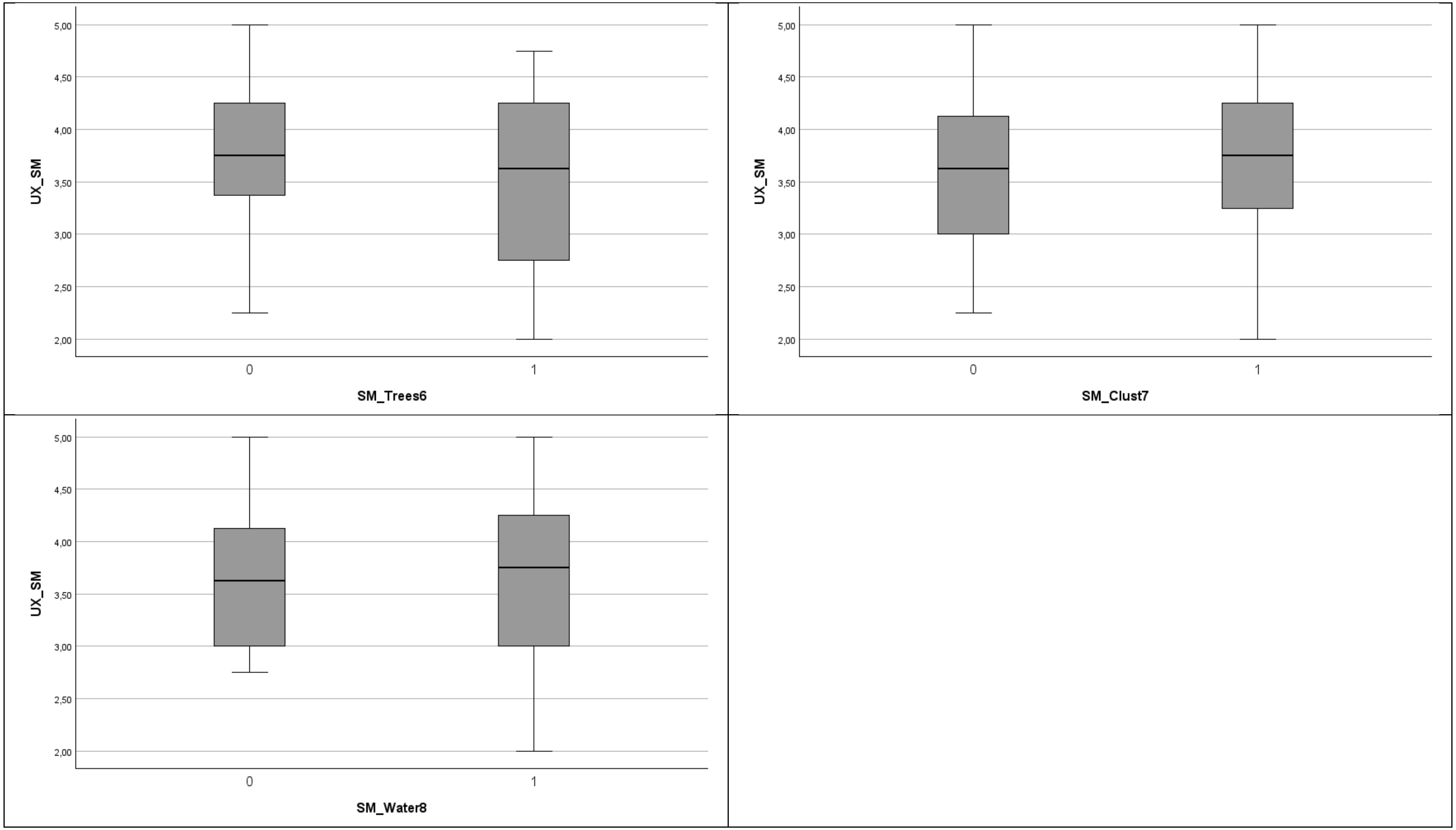




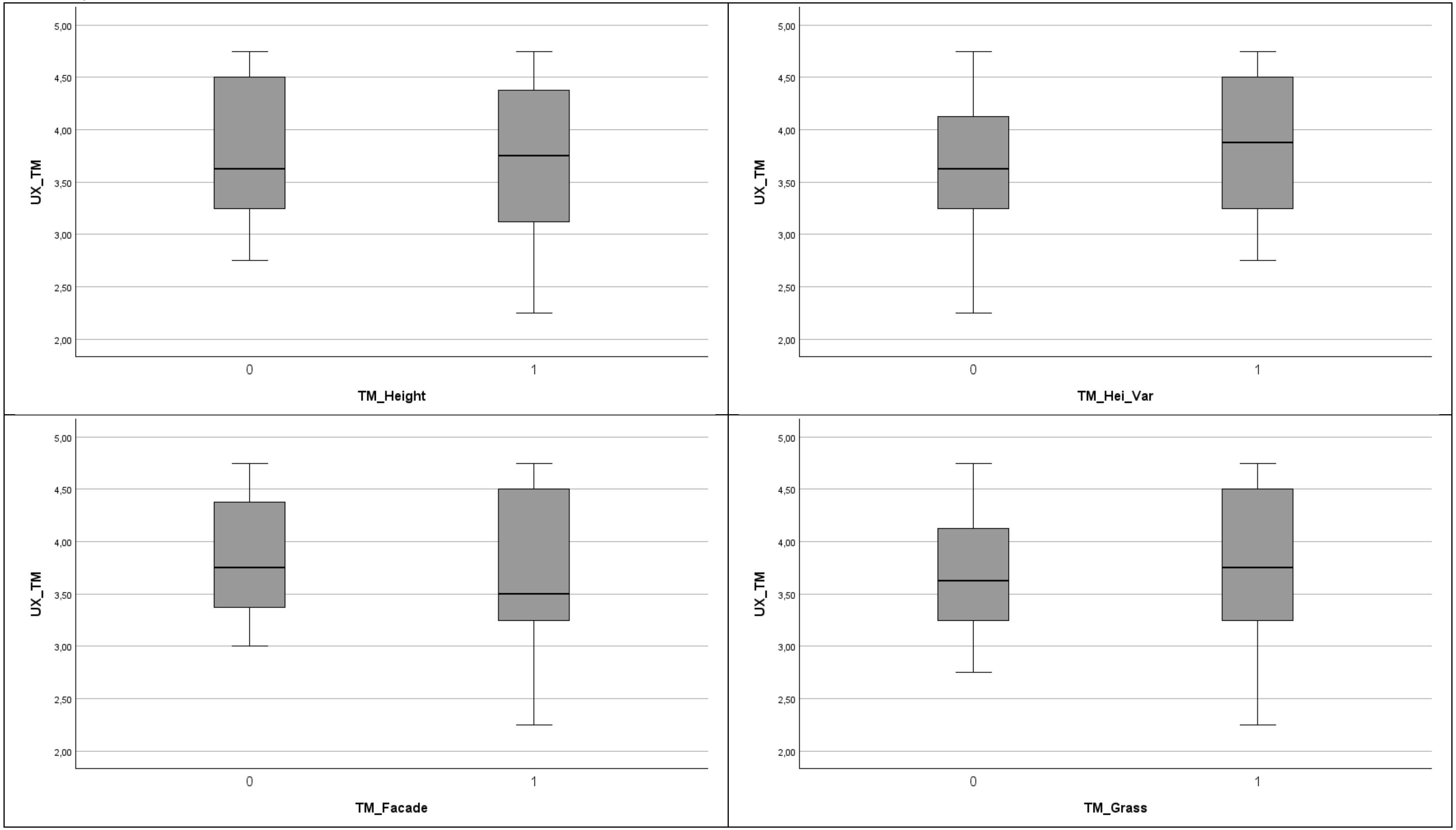
5,00
4,50
4,00
3,50
3,00
2,50
UX_FM
0
1
FM_Trees
FM_Clust
28
FM_Water

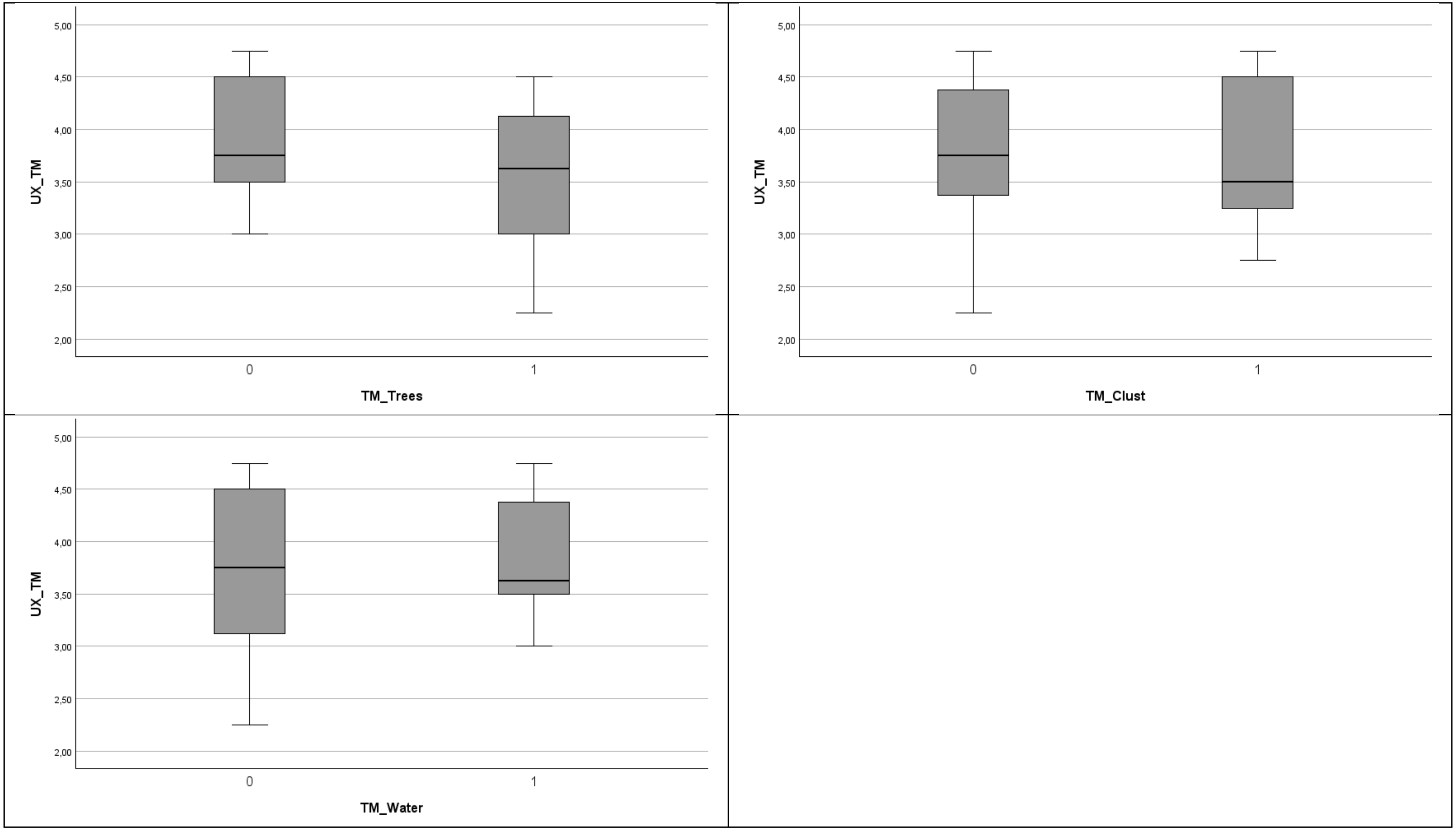
User-experience Second Visited Models versus the Environmental Characteristics




UX_SM
5,00
4,50
4,00
3,50
3,00
2,50
2,00
0
1
SM_Trees6
UX_SM
5,00
4,50
4,00
3,50
3,00
2,50
2,00
0
1
SM_Clust7
UX_SM
5,00
4,50
4,00
3,50
3,00
2,50
2,00
0
1
SM_Water8

User-experience Third Visited Models versus the Environmental Characteristics




UX_TM
5,00
4,50
4,00
3,50
3,00
2,50
2,00
0
1
TM_Trees
TM_Clust
TM_Water

## Appendix H. Coefficients Tables Panel Regression

*Table 43 Coefficients table panel regression*

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3,333 | ,307 | | 10,862 | <,001 |
| | ID=2.0 | 1,333 | ,434 | ,331 | 3,072 | ,003 |
| | ID=3.0 | -,250 | ,434 | -,062 | -,576 | ,567 |
| | ID=4.0 | ,833 | ,434 | ,207 | 1,920 | ,059 |
| | ID=5.0 | -,083 | ,434 | -,021 | -,192 | ,848 |
| | ID=6.0 | 1,083 | ,434 | ,269 | 2,496 | ,015 |
| | ID=7.0 | ,083 | ,434 | ,021 | ,192 | ,848 |
| | ID=8.0 | ,333 | ,434 | ,083 | ,768 | ,445 |
| | ID=9.0 | ,500 | ,434 | ,124 | 1,152 | ,254 |
| | ID=10.0 | -,167 | ,434 | -,041 | -,384 | ,702 |
| | ID=11.0 | -,667 | ,434 | -,166 | -1,536 | ,129 |
| | ID=12.0 | 1,006E-15 | ,434 | ,000 | ,000 | 1,000 |
| | ID=13.0 | 1,006E-15 | ,434 | ,000 | ,000 | 1,000 |
| | ID=14.0 | ,250 | ,434 | ,062 | ,576 | ,567 |
| | ID=15.0 | ,750 | ,434 | ,186 | 1,728 | ,089 |
| | ID=16.0 | ,750 | ,434 | ,186 | 1,728 | ,089 |
| | ID=17.0 | 8,939E-16 | ,434 | ,000 | ,000 | 1,000 |
| | ID=18.0 | ,417 | ,434 | ,103 | ,960 | ,341 |
| | ID=19.0 | 1,250 | ,434 | ,310 | 2,880 | ,005 |
| | ID=20.0 | -,250 | ,434 | -,062 | -,576 | ,567 |
| | ID=21.0 | ,750 | ,434 | ,186 | 1,728 | ,089 |
| | ID=22.0 | ,333 | ,434 | ,083 | ,768 | ,445 |
| | ID=23.0 | ,333 | ,434 | ,083 | ,768 | ,445 |
| | ID=24.0 | 1,417 | ,434 | ,352 | 3,264 | ,002 |
| | ID=25.0 | 1,006E-15 | ,434 | ,000 | ,000 | 1,000 |
| | ID=26.0 | -,250 | ,434 | -,062 | -,576 | ,567 |
| | ID=27.0 | ,250 | ,434 | ,062 | ,576 | ,567 |
| | ID=28.0 | ,833 | ,434 | ,207 | 1,920 | ,059 |
| | ID=29.0 | 1,006E-15 | ,434 | ,000 | ,000 | 1,000 |
| | ID=30.0 | 1,333 | ,434 | ,331 | 3,072 | ,003 |
| | ID=31.0 | 1,333 | ,434 | ,331 | 3,072 | ,003 |
| | ID=32.0 | ,333 | ,434 | ,083 | ,768 | ,445 |
| 2 | (Constant) | 3,511 | ,356 | | 9,861 | <,001 |
| | ID=2.0 | 1,196 | ,444 | ,297 | 2,693 | ,009 |
| | ID=3.0 | -,389 | ,442 | -,097 | -,880 | ,383 |
| | ID=4.0 | ,809 | ,427 | ,201 | 1,893 | ,063 |
| | ID=5.0 | -,131 | ,436 | -,032 | -,300 | ,765 |
| | ID=6.0 | ,969 | ,444 | ,241 | 2,185 | ,033 |
| | ID=7.0 | ,091 | ,443 | ,022 | ,205 | ,839 |
| | ID=8.0 | ,333 | ,419 | ,083 | ,796 | ,429 |
| | ID=9.0 | ,263 | ,427 | ,065 | ,617 | ,540 |
| | ID=10.0 | ,011 | ,435 | ,003 | ,026 | ,980 |
| | ID=11.0 | -,648 | ,435 | -,161 | -1,492 | ,141 |
| | ID=12.0 | -,115 | ,435 | -,029 | -,264 | ,793 |
| | ID=13.0 | -,114 | ,434 | -,028 | -,264 | ,793 |
| | ID=14.0 | ,080 | ,435 | ,020 | ,185 | ,854 |
| | ID=15.0 | ,782 | ,437 | ,194 | 1,791 | ,079 |
| | ID=16.0 | ,757 | ,435 | ,188 | 1,743 | ,087 |
| | ID=17.0 | -,023 | ,436 | -,006 | -,054 | ,957 |

| | | | | | |
|---|---|---|---|---|---|
| ID=18.0 | ,247 | ,435 | ,061 | ,568 | ,572 |
| ID=19.0 | 1,032 | ,443 | ,256 | 2,327 | ,024 |
| ID=20.0 | -,152 | ,427 | -,038 | -,356 | ,723 |
| ID=21.0 | ,701 | ,434 | ,174 | 1,614 | ,112 |
| ID=22.0 | ,153 | ,435 | ,038 | ,352 | ,726 |
| ID=23.0 | ,376 | ,427 | ,093 | ,881 | ,382 |
| ID=24.0 | 1,448 | ,437 | ,360 | 3,318 | ,002 |
| ID=25.0 | -,073 | ,434 | -,018 | -,169 | ,867 |
| ID=26.0 | -,388 | ,444 | -,096 | -,873 | ,386 |
| ID=27.0 | ,013 | ,427 | ,003 | ,031 | ,975 |
| ID=28.0 | ,809 | ,427 | ,201 | 1,893 | ,063 |
| ID=29.0 | ,080 | ,426 | ,020 | ,188 | ,852 |
| ID=30.0 | 1,366 | ,444 | ,339 | 3,073 | ,003 |
| ID=31.0 | 1,456 | ,435 | ,362 | 3,346 | ,001 |
| ID=32.0 | ,072 | ,435 | ,018 | ,166 | ,869 |
| Height | ,209 | ,121 | ,149 | 1,727 | ,090 |
| Height Variation | ,109 | ,124 | ,078 | ,878 | ,384 |
| Façade | -,048 | ,116 | -,034 | -,417 | ,678 |
| Grass | -,193 | ,120 | -,138 | -1,612 | ,113 |
| Trees | -,210 | ,122 | -,150 | -1,723 | ,090 |
| Clustering | ,073 | ,120 | ,052 | ,604 | ,548 |
| Water | -,182 | ,124 | -,130 | -1,468 | ,148 |

*Table 44 Tests of Between-Subjects Effects of panel regression.*

**Tests of Between-Subjects Effects**

Dependent Variable: UX_SUM

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 513,674[a] | 38 | 13,518 | 3,211 | <,001 | ,682 |
| Intercept | 2189,755 | 1 | 2189,755 | 520,173 | <,001 | ,901 |
| Height | 12,556 | 1 | 12,556 | 2,983 | ,090 | ,050 |
| Height Variation | 3,245 | 1 | 3,245 | ,771 | ,384 | ,013 |
| Façade | ,731 | 1 | ,731 | ,174 | ,678 | ,003 |
| Grass | 10,934 | 1 | 10,934 | 2,597 | ,113 | ,044 |
| Trees | 12,499 | 1 | 12,499 | 2,969 | ,090 | ,050 |
| Clustering | 1,538 | 1 | 1,538 | ,365 | ,548 | ,006 |
| Water | 9,071 | 1 | 9,071 | 2,155 | ,148 | ,036 |
| ID | 459,882 | 31 | 14,835 | 3,524 | <,001 | ,657 |
| Error | 239,951 | 57 | 4,210 | | | |
| Total | 22174,000 | 96 | | | | |
| Corrected Total | 753,625 | 95 | | | | |

*Table 45 Parameter Estimates of panel regression.*

**Parameter Estimates**

Dependent Variable: UX_SUM

| Parameter | B | Std. Error | t | Sig. | 95% Confidence Interval | | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | |
| Intercept | 14,334 | 1,301 | 11,016 | <,001 | 11,729 | 16,940 | ,680 |
| Height | ,836 | ,484 | 1,727 | ,090 | -,133 | 1,805 | ,050 |
| Height Variation | ,437 | ,498 | ,878 | ,384 | -,560 | 1,433 | ,013 |
| Façade | -,193 | ,463 | -,417 | ,678 | -1,119 | ,734 | ,003 |
| Grass | -,771 | ,479 | -1,612 | ,113 | -1,730 | ,187 | ,044 |
| Trees | -,840 | ,487 | -1,723 | ,090 | -1,815 | ,136 | ,050 |
| Clustering | ,290 | ,480 | ,604 | ,548 | -,671 | 1,251 | ,006 |
| Water | -,727 | ,495 | -1,468 | ,148 | -1,718 | ,265 | ,036 |
| ID=1 | -,289 | 1,741 | -,166 | ,869 | -3,776 | 3,198 | ,000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ID=2 | 4,493 | 1,745 | 2,575 | ,013 | ,999 | 7,987 | ,104 |
| ID=3 | -1,847 | 1,709 | -1,080 | ,285 | -5,269 | 1,576 | ,020 |
| ID=4 | 2,946 | 1,707 | 1,726 | ,090 | -,472 | 6,365 | ,050 |
| ID=5 | -,812 | 1,778 | -,457 | ,650 | -4,371 | 2,748 | ,004 |
| ID=6 | 3,589 | 1,745 | 2,056 | ,044 | ,094 | 7,083 | ,069 |
| ID=7 | ,073 | 1,743 | ,042 | ,967 | -3,418 | 3,564 | ,000 |
| ID=8 | 1,044 | 1,741 | ,600 | ,551 | -2,443 | 4,531 | ,006 |
| ID=9 | ,765 | 1,709 | ,447 | ,656 | -2,657 | 4,186 | ,003 |
| ID=10 | -,244 | 1,777 | -,137 | ,891 | -3,803 | 3,314 | ,000 |
| ID=11 | -2,883 | 1,737 | -1,660 | ,102 | -6,360 | ,594 | ,046 |
| ID=12 | -,749 | 1,748 | -,428 | ,670 | -4,248 | 2,751 | ,003 |
| ID=13 | -,747 | 1,705 | -,438 | ,663 | -4,162 | 2,668 | ,003 |
| ID=14 | ,032 | 1,705 | ,019 | ,985 | -3,382 | 3,447 | ,000 |
| ID=15 | 2,838 | 1,785 | 1,590 | ,117 | -,737 | 6,412 | ,042 |
| ID=16 | 2,741 | 1,740 | 1,575 | ,121 | -,743 | 6,224 | ,042 |
| ID=17 | -,383 | 1,780 | -,215 | ,830 | -3,947 | 3,181 | ,001 |
| ID=18 | ,699 | 1,705 | ,410 | ,683 | -2,715 | 4,113 | ,003 |
| ID=19 | 3,837 | 1,708 | 2,247 | ,029 | ,418 | 7,257 | ,081 |
| ID=20 | -,898 | 1,776 | -,506 | ,615 | -4,454 | 2,658 | ,004 |
| ID=21 | 2,515 | 1,742 | 1,444 | ,154 | -,974 | 6,004 | ,035 |
| ID=22 | ,323 | 1,708 | ,189 | ,851 | -3,097 | 3,743 | ,001 |
| ID=23 | 1,215 | 1,772 | ,686 | ,496 | -2,333 | 4,763 | ,008 |
| ID=24 | 5,504 | 1,785 | 3,084 | ,003 | 1,930 | 9,079 | ,143 |
| ID=25 | -,582 | 1,704 | -,342 | ,734 | -3,995 | 2,830 | ,002 |
| ID=26 | -1,840 | 1,745 | -1,055 | ,296 | -5,334 | 1,654 | ,019 |
| ID=27 | -,235 | 1,709 | -,138 | ,891 | -3,657 | 3,186 | ,000 |
| ID=28 | 2,946 | 1,707 | 1,726 | ,090 | -,472 | 6,365 | ,050 |
| ID=29 | ,031 | 1,738 | ,018 | ,986 | -3,450 | 3,512 | ,000 |
| ID=30 | 5,175 | 1,781 | 2,905 | ,005 | 1,608 | 8,742 | ,129 |
| ID=31 | 5,535 | 1,773 | 3,121 | ,003 | 1,984 | 9,086 | ,146 |
| ID=32 | 0[a] | . | . | . | . | . | . |