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The Study of Wayfinding by using Virtual Reality

Exploration of how shadows affect human wayfinding

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Master thesis
(TBA4925 - Geomatics, Master thesis)

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for
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BACKGROUND

Over the last years different models of low-cost Virtual Reality equipment have been available. These tools have been developed and produced for the gaming industry. However, an open programming interface makes the equipment useful for different tasks. As for example the study of human navigation, where natural the environment is substituted by VR. In VR different it is easier to control different factors that can influence on the human navigation

TASK DESCRIPTION

The student is supposed to make a small city model in VR, where different parameters as for example shadows from buildings, building texture and visibility of landmarks are easy adjustable. Next the student is supposed to set up an experiment, where human subjects will be invited to participate in order to study how actual factors are influencing on the navigation.

Specific tasks:

- Study relevant literature for the chosen subject.
- Study use of virtual reality and its application.
- Construct a small city model
- Implement a map of the city model to support the navigation by the participants in the experiment
- Design an experiment where the influence of the environmental variables can be studied
- Analyse the results by using standard statistical methods

ADMINISTRATIVE/GUIDANCE

The work on the Master Thesis starts on January 15th, 2022

The thesis report as described above shall be submitted digitally in INSPERA at the latest at June 19th, 2022

Supervisors at NTNU and professor in charge:
Terje Midtbø

Trondheim, January, 2022

Abstract

Wayfinding tasks play a significant role in people's daily lives. Wayfinding is important not only when traveling to unfamiliar places but also when traveling to familiar places such as work or school. This thesis compares the wayfinding performance in city models with shadows vs. city models without shadows in virtual reality.

The thesis introduces wayfinding in both the real world and Virtual Environments, followed by a deeper look into the theory of virtual reality and Oculus Quest. An experiment with 20 participants was conducted using the virtual reality system Oculus Quest. The participants performed a task twice in two Virtual Environments, one with shadow and one without shadow. The participants were asked to walk a path and, at the destination, point to the direction of the origin. The metrics measured were the degrees of error between the correct direction line and the direction pointed. These were analyzed by using standard statistical methods and further discussed. Two questionnaires were also filled out to map the participants' spatial abilities and level of presence. The correlation between the questionnaires and the results gathered was calculated and discussed.

The results from the experiment were proven to be not significant. However, there was a higher difference in the standard deviation between the path walked first and the path walked last, indicating that the participants learned how to conduct the experiment in order to achieve better results after one attempt.

For further work, an experiment with another approach for guiding and other metrics should be measured to see if there is a better way to look at the effect shadows have on navigation. In addition, it could be interesting to look at how shadows affect wayfinding performance within a younger and an older generation, as the participants commented that they mostly use digital maps for wayfinding.

Sammendrag

Navigasjonsoppgaver spiller en betydelig rolle i folks daglige liv. Navigering er viktig ikke bare når man reiser til ukjente steder, men også når man reiser til familiøre steder slik som jobb eller skole. Denne oppgaven bruker virtuell virkelighet for å studere hvordan skygger påvirker navigasjon.

Oppgaven introduserer navigasjon i både den virkelige verden og i virtuelle miljøer, etterfulgt av en nærmere titt på teorien om virtuell virkelighet og virtuell virkelighet-systemet Oculus Quest. Det ble utført et eksperiment med 20 deltakere ved bruk av dette systemet. Deltakerne utførte en oppgave to ganger i to ulike virtuelle miljøer, ett med skygge og ett uten skygge. Deltakerne ble bedt om å følge en rute og, ved destinasjonen, peke i retningen de kom fra. Vinkelen mellom riktig retningslinje og retningslinjen som ble pekt, ble målt og resultatene ble analysert ved bruk av standard statistiske metoder før de til slutt ble diskutert. Deltakerne fylte også ut to spørreskjemaer for å kartlegge deltakernes romlige egenskaper og følelse av tilstedeværelse. Korrelasjonen mellom data fra spørreskjemaene og de innsamlede resultatene ble beregnet og diskutert.

Resultatene fra eksperimentet viste seg å ikke være signifikante. Det var imidlertid mer forskjell i standardavviket mellom første og andre, noe som indikerer at deltakerne lærte hvordan de skulle gjennomføre eksperimentet for å oppnå bedre resultater etter å ha gått gjennom én rute.

For videre arbeid bør et eksperiment med en annen tilnærming for guiding og andre beregninger måles for å se om det er en bedre måte å se på effekten skygger har på navigasjon. I tillegg kunne det vært interessant å se på hvordan skygger påvirker navigeringsevnen for en yngre og en eldre generasjon, da deltakerne kommenterte at de stort sett er avhengig av digitale kart for navigasjon.

Preface

This paper is a master's thesis written for the Department of Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU). It is a part of the course TBA4925 at the study program Engineering and ICT - Geomatics and was written in the spring of 2022.

I would like to thank my supervisor Terje Midtbø for his help and guiding throughout this period, in addition to providing the technical equipment needed to complete the experiment.

I would also like to thank my friends and family for all of their support during these times. I would especially like to thank my friend Helene Molberg and my little brother for helping me when I was stuck and proofreading the thesis. Without their help and support this thesis would not be the same.

Table of Contents

List of Figures

List of Tables

Abbreviations

AR	Augmented Reality
BOOM	Binocular Omni-Orientation Monitor
DoF	Degrees of Freedom
FSD	Floor-supported Display
HMD	Head-mounted display
HSD	Hand-Supported Display
OSM	Open Street Map
SBSOD	Santa Barbara Sense of Direction Scale
SDK	Software Development Kit
VCASS	Visually Coupled Airborne Systems Simulator
VE	Virtual Environment
VR	Virtual Reality
XR	Mixed Reality

Chapter 1

Introduction

Orienting and navigating through environments are skills that are employed regularly in a range of situations. It is utilized in most people's daily activities, such as driving in a city, walking in a park, or moving within a building. People can make wayfinding decisions that assist them in navigating their way through various environments. For example, when visiting new places, one learns to recognize landmarks or significant features in the surroundings. This information helps people find their way from point A to point B and is essential for avoiding becoming lost in unfamiliar environments.

Wayfinding in virtual environments (VEs) is a relatively new concept and is, unlike wayfinding in the real-world, unfamiliar to most people. Through the technology of virtual reality (VR), it is possible to explore an entirely new world without physically being there. VR is a new technical breakthrough that simplifies the completion of several tasks. VR makes it possible to construct a VE remarkably similar to the actual world. Later studies have demonstrated that, while the quality and immersion are still somewhat lacking, VR gives researchers controlled surroundings to conduct various tests. As a result, VR is becoming more beneficial in various sectors, including research, entertainment, and education [64]. The ability to control the environment in a way that is impossible in the real-world makes VR an excellent aid in conducting experiments to test wayfinding performances. This thesis wants to look into how shadows affect wayfinding, and

as shadows cannot be turned off in the real-world, VR helps do so.

In this thesis, the VR system Oculus Quest is used to perform wayfinding tasks in a VE. By creating two different city models, one with shadow and one without shadow, an experiment was planned in order to answer the following research questions:

1. Do shadows from buildings and surroundings affect the wayfinding experience?

2. Do spatial abilities and level of presence affect performance in wayfinding tasks differently with shadows than without shadows?

Spatial abilities may influence an individual's wayfinding performance, thus they are gathered and retrieved and compared to each participant's wayfinding performance using the Santa Barbara Sense of Direction Scale (SBSOD).

The primary goal of VR is to provide the user with the sensation of actually being in the VE. Feeling like one belongs in the environment may lead to better performance in the actual world. The amount of presence felt by the participants is recorded by using a presence questionnaire. After this the results were compared to the results of the wayfinding performance to determine the if it was impacted by the level of presence.

In order to understand the academic background of the thesis, this report will first take a deeper look into the previous research in the field of wayfinding in VEs. This will be followed by explaining the theory regarding VR, the Oculus Quest, and wayfinding. The approach for developing VEs and planning the experiment will also be described. Finally, the experiment data will be presented and discussed before concluding the paper.

Chapter 2

Theoretical Background

This chapter aims to provide the reader with the concepts behind the technology addressed in this project and the necessary information and relevant theory. This chapter can be divided into three main categories:

- Wayfinding

- Virtual Reality

- Oculus Quest

The first section explores previous research amd theory in the field of wayfinding, both in the real-world and in VEs. The second part offers an overview of definitions, history, concepts, and how VR can be used to obtain important information about users in test environments. The last section is about understanding how Oculus Quest works and how to use the device for collecting test environments and data in future works.

2.1 Wayfinding

From the beginning of time, people have been using wayfinding techniques to navigate from one place to another [46]. The term "Wayfinding" was first introduced by Kevin Lynch in 1960 [68], and has since been defined in different ways. Long and Hill [32] explained the term as a process for navigating through

environments and traveling to locations along relatively direct paths. Passini [46] writes, "Wayfinding describes a person's ability, both cognitive and behavioral, to reach spatial destinations." Golledge et al. [22] provides the definition of wayfinding as "a purposive, directed, and motivated process of moving from an origin to a destination." The eventual goal of human wayfinding is to find the way from one place to another [58].

For this thesis, the author will examine previous research on human wayfinding in the real-world, followed by wayfinding in VEs.

2.1.1 Real-World

Wayfinding in the physical world requires maneuvering and navigation. Maneuvering concerns the process of trying to position oneself at a desired location. Navigation, on the other hand, is more about the cognitive process, such as the skills associated with landmark recognition, route memorization, and developing and maintaining one's sense of direction in the world [48]. When first introduced to a new location, one learns to recognize landmarks or prominent characteristics in the surroundings [22]. Declarative knowledge structures retain properties such as the texture, form, and orientation of specific objects, allowing us to access this knowledge [48].

The wayfinding tactics and requisite cognitive capacities of the user are different depending on whether they are outdoors or indoors. When determining people's movement patterns, the spatial layout qualities of objects are more important in the outdoor environment. In metropolitan surroundings, people tend to alter their orientation as they go. This is due to the fact that open areas may feature landmarks that can be seen from several angles. People can also monitor which direction they came from in relation to other objects on the horizon, such as trees or buildings. As a result, the exterior environment is described as continuous, while the interior rooms are perceived as a series of unique happenings, distinctly separated from the outside world. In addition, when navigating indoors, landmarks in the skyline and vectors like shadows and wind are not available to provide a bearing [8].

The basic process of wayfinding, according to Lidwell et al. [31], contains the same four steps whether one is navigating in the mountains, a website, or a big city. The four steps are Orientation, Route Decision, Route Monitoring, and Destination Recognition.

In addition to the four steps, it may be beneficial to explore the many sorts of wayfinding tasks that may be performed. Among the various potentially useful ways of classifying wayfinding activities, Allen [1] suggests that the following three-category approach based on functional goals is of the highest heuristic value:

- Travel with the goal of reaching a familiar destination

- Exploratory travel with the goal of returning to a familiar starting point

- Travel with the goal of reaching an unfamiliar destination

These three kinds of wayfinding tasks can be conducted using several methods, some of which are task-specific and others that are task-universal [1]. Figure 2.1 depicts the methods used for each navigation task.

Wayfinding means	Wayfinding tasks		
	Travel to familiar destinations	Exploratory travel	Travel to novel destinations
Oriented search	X	X	X
Following a marked trail	X	X	X
Piloting between landmarks	X	X	X
Path integration	X	X	
Habitual locomotion	X		
Referring to a cognitive map	X	X	X

Figure 2.1: Wayfinding means used for each wayfinding task

Source: Allen [1]

The two primary areas of research in the field of wayfinding are external information (environmental factors) and internal information (cognitive representation). Norman [45] characterized them as "knowledge in the world" and "knowledge in the mind," both of which are required in people's everyday lives

[64]. Furthermore, according to recent studies, wayfinding approaches in the real world can also be used to assist people in successfully navigating VE's [13]. This will be further explored in the next section.

2.1.2 VR

One of the most important aspects of VR is its flexibility. Using VR in wayfinding experiments allows researchers to create environments appropriate for the study's objectives while maintaining better control over various variables. Retaining control over variables when using real-world surroundings as an interactive environment is challenging to achieve consistently. Furthermore, using this technology, changes to the experimental environment may be done at a low cost and in a shorter period of time [64].

In earlier research, experiments were conducted using a desktop-based VR system [64]. Using a non-immersive VR system to explore wayfinding can generate a situation in which participants do not feel completely immersed in the experience. As a result, the differences between real-world and virtual navigation behaviors may increase. While interacting with desktop-based VR, participants would not be able to explore the VE as they would in the real-world. They would not be able to walk in one direction while at the same time facing the other. This is, for instance, because locomotion often is based on head position; a limited field of view might impair a user's sensation of presence.

According to the findings of a study done by Ewart and Johnson [16], even though the activity was finished faster in VR than in reality, most participants felt it was slower, despite the walking speed being adjusted to match an average walking pace. They explored how this may be due to the visible lack of activity and effort, as well as the lack of actual movement. This is something to keep in mind for future study so that tweaks to the experiment may be made to provide a realistic perception of travel speed and distance compared to reality.

Navigation and wayfinding, as stated by Ewart and Johnson [16], is one area with the potential for increased use of new digital technology in understanding the

usage of buildings. There is potential to develop tools and approaches to study wayfinding habits and utilize that information to design new and improve existing buildings.

Early studies on wayfinding in VR, such as the research by Ruddle et al. [51], depended on technology that struggled to recreate a feeling of reality. The VE was viewed as a unique experience in itself. This is an important issue today since VR is still a young and rapidly evolving technology, and research into how it is perceived is having trouble keeping up.

2.2 Virtual Reality

In this section, the author will take a closer look at the concept of VR. The concept will first be defined before looking at the history, what it is, the technical aspects, and in which fields it can be applied.

2.2.1 Definition

As VR is a relatively new technology, researchers and users have different definitions of the concept. For example, Bardi [4] has defined VR as "The use of computer technology to create a simulated experience that can be similar to or completely different from the real-world." Another broader definition of VR can be found in the book "Understanding Virtual Reality." There it is defined as "A medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)." The definition consists of what is described as "The four elements of Virtual Reality"; Virtual world, Immersion, Sensory Feedback, and Interactivity [53]. What is repeated is that the user is brought into a virtual world that has been designed to be as realistic as possible for the creator's purposes.

2.2.2 History

Multiple mediums have been utilized throughout history to express and experience ideas [53]. Previously, one could only encounter the imaginative world in one's mind. Conveying such a world through some medium allowed other individuals to experience the author's thoughts and ideas. Humans, such as authors, musicians, and other creative individuals, have long imagined alternate worlds in their imaginations. Later, such worlds expanded due to the introduction of technologies such as television, movies, and video games. Several writers have offered several timelines to summarize the evolution of VR. (Sherman and Craig [53], Mazuryk and Gervautz [33], Cruz-Neira [9], Gigante [20]). Table 2.1 lists some of the significant milestones.

Year	Milestone
1929	Edward Link created a basic mechanical flight simulator to educate pilots in a static environment.
1962	Morton Heilig created and patented Sensorama, a multimodal experience display system.
1971	GROPE, the first force-feedback system prototype, was developed at the University of North Carolina.
1982	The Visually Coupled Airborne Systems Simulator (VCASS), an advanced flight simulator, was developed by Thomas Furness.
1987	BOOM was designed and prototyped. This is a box with two eyeholes through which the user could navigate a VE. In addition, it had a mechanical arm that allowed one to interact with the box.
1989	The phrase "Virtual Reality" was introduced when RB-2 was announced as a complete VR system.
1990+	Augmented Reality (AR) became a focus for many research projects. This technology enriches the physical world by adding virtual data to the real-world.
2010	Introduction of the stereoscopic 3D mode of Street View by Google.
2014	Meta Platforms purchased Oculus VR, Sony began development on Project Morpheus, Google released Cardboard, and Samsung launched Gear VR.
2019	Oculus Quest, the first standalone VR headset, was released

Table 2.1: Milestones of VR evolution

As seen above, the technology is rapidly evolving. The popularity of VR has also escalated ever since the first Oculus Rift launched in 2012. In addition to a vast amount of video games and software developed specifically for VR, the technology is evolving so quickly that new and improved equipment is released every year.

2.2.3 Degrees of Freedom

Degrees of Freedom (DoF) is a concept that is widely used when talking about VR. VR [65] writes that "The degrees of freedom refers to the number of basic ways a rigid object can move through three-dimensional space." There is a total of six DoF, with three main axes and three secondary axes, called the translational- and rotational axis. In VR, we generally talk about 3DoF or 6DoF. Head-tracking with 3DoF means that one can only track either the translational or the rotational movement. With 6DoF, on the other hand, one can track both [30]. Figure 2.2 illustrates the three translational axis'. And figure 2.3 illustrates the three rotational axis'.

ELEVATING

Elevation is where a person **moves up or down** (i.e. when bending down or standing up)

STRAFING

Strafe is where a person **moves left or right** (i.e. when sidestepping)

SURGING

Surge is where a person **moves forwards or backwards**(i.e. when walking)

Figure 2.2: The translational axis

Source: [30]

ROLLING

Rolling is where the head **pivots side to side** (i.e. when peeking around a corner)

PITCHING

Pitch is where the head **tilts along a vertical axis** (i.e when looking up or down)

YAWING

Yaw is where the head **swivels along a horizontal axis** (i.e when looking left or right)

Figure 2.3: The rotational axis

Source: [30]

This implies that a 6DoF can tell whether a user has moved about in the virtual world by observing how they move around in the actual world.

2.2.4 VR Graphic Displays

Burdea and Coiffet [7] defines a graphical display as "A computer interface that presents synthetic world images to one or several users interacting with the virtual world." When generating reality and a sense of immersion, image quality plays an essential role, in addition to a high frame rate. A high refresh rate, high resolution, high brightness, and contrast level, and a wide field of vision are all desirable features in a display. At the same time, it should not be at the cost of wearability. It should be simple to use and have a low weight [33].

Burdea and Coiffet [7] divides the various output displays into two categories:

- Personal displays - Displays meant for a single user.

- Large volume displays - Displays meant for several users located at the same place.

In this thesis, we focus on the first one, the personal displays. These are divided into three types, which are as follows:

HMD - Head-Mounted Display

The HMDs are probably the objects most associated with VR and the most common VR device due to their low cost and size. They are sometimes referred to as "VR glasses" since the device can be placed on the user's head like a helmet with binoculars covering their eyes. HMDs are designed to ensure that no matter the direction a user might look, the monitor always stays in front of the user's eyes. The device is made up of sensors that can detect the rotation of the user's head and a screen that displays the VE. HMDs have also been used in military, medical, and engineering applications, to mention a few [55].

HSD - Hand-Supported Displays

The HSDs are graphic displays the users have to hold in their hands. As they both display the VE through binoculars, the HSDs share many features with the HMDs. However, the HSDs also allow interaction with the environment through push buttons. The new version of the HMD Oculus, Oculus Quest, also has this option, as one can see later in this thesis [7].

FSD - Floor-Supported Displays

The Floor-Supported display is an earlier version of the HMDs. They have a mechanical arm that acts as a sensor to register head movement. Using a technical arm removes any time delay when moving the head, making the image. However, due to the arm's definite length, ut also makes it impossible to move in a large area [7]. An example of a FSD is BOOM, as described in table 2.1 in section 2.2.2.

2.2.5 Motion Sickness

One known issue with VR is the risk of motion sickness. Hettinger and Riccio [25] defined motion sickness as "a syndrome that occasionally occurs when physically stationary individuals view compelling visual representations of self-motion." Although there is currently little knowledge about the underlying physiological causes, there is evidence that a mismatch between motion induces the sickness sensed visually and through the vestibular system. It occurs mainly in VR when the visual system perceives apparent motion while the vestibular system alerts the brain that there is no movement and the body is standing still [47]. Anecdotal reports make it clear that many users can rapidly transition from a pleasurable sense of immersion to an intense sense of discomfort, disorientation, and nausea [42]. In an experiment setting, this may lead to an abortion of observations, which again may worsen the results.

It is important to consider the potential occurrence of motion sickness when conducting an experiment in a VE. In the experiment described later in the thesis, the participants were encouraged to indicate if they started feeling sick. They were also to let the author know if they needed to take a break or abort the experiment.

2.2.6 Applications of VR

To better understand what VR may be used for, it is necessary to investigate the many uses of VR throughout history. Flexibility is one of the advantages of VR. Researchers can create virtually anything through coding and modeling. The VE is created from scratch, making it possible to create a Scene containing the exact elements needed for an experiment. Only the authors' imagination limits the VE's potential. It could be similar to reality or deviate considerably [4].

Navigation and spatial data are one area of study in which VR's ability to control the environment could benefit. One common problem when conducting experiments within this field is that they must be performed outside, making them dependent on unpredictable weather. It is therefore challenging to ensure that researchers will not encounter bad weather, high levels of noise, or humans otherwise interfering with the experiment.

Driving lessons are another example of an area where the technologies of VR could be helpful. According to Motion [41], VR Driver Training with the fully-immersive environment only VR can provide has been proven to teach drivers certain abilities. Way, a Norwegian traffic school, employs this technology to teach students basic driving abilities, which helps them prepare for real-world traffic. Unlike traditional driving lessons, students can rehearse risky and unplanned situations several times [67]. This is just one example of how VR is affecting not only research but also everyday activities, making them easier and more effective.

The world of real estate has also found use cases for VR. For example, realtors needing fewer trips to the house and reducing costs and time spent are some of the benefits of using VR in real estate. According to Goldman-Sachs [21], it is estimated that 1.4 million realtors will be using this technology by 2025, accounting for the vast majority of all professionals in this industry. Meanwhile, consumers have access to a virtual window-shop, which allows for near unlimited estate customizations [49].

2.3 Oculus Quest

The Oculus Quest is the first stand-alone VR headset featuring 6DoF inside-out tracking with two 6DoF controllers [26]. It allows the user to experience VR while moving around without using a computer, wires, tethers, or external sensors.

2.3.1 Components

Oculus Quest is an original all-in-one gaming system designed for VR created by Meta. It is an HMD VR system that serves as a standalone system. This implies that the user will have everything they need to visit virtual worlds inside the box. However, in the beginning, they will need the Oculus program on their phone to help set it up. The system package contains the following components:

1. **Head-mounted display:** The HMD serves as the screen.

2. **Touch controllers:** Two wireless controllers that allow the user to interact with and move in the VE.

3. **AA batteries:** For powering the controllers.

4. Power adapter and a connection wire for developing purposes.

5. **Frame friendly spacer:** Used for packing purposes.

The different components in the Oculus Quest system are shown in figure 2.4.

Figure 2.4: The components in the Oculus Quest Package

Source: Baker [3]

2.3.2 Technical Specifications

Rogers [50] have listed the technical specifications of the Oculus Quest. These are listed in table 2.2:

Oculus Quest

Display panel	OLED
Display resolution	1440 x 1600 per eye
Refresh rate	72 Hz
CPU	Qualcomm Snapdragon 835
GPU	Qualcomm Adreno 540
RAM	4GB
Audio	Fully integrated open ear
Battery	Litium-ion, up to 2-3 hours of playing time, depending on what is being played
Degree of Freedom	6-DoF
Weight	571g
Lens Distance	Adjustable

Table 2.2: Technical Specifications of Oculus Quest

2.3.3 Advantages

According to Jurkic [28], when the Oculus Quest was first released in 2019, it was the only actual all-in-one VR device. It brought forth the ultimate motion-sensing technology, like the one present with fully-fledged VR headsets. The fact that the Oculus Quest is cordless is one of its most significant advantages. The user not having to worry about accidentally pulling the cord out makes the experience of using the headset better. Pulling the cord out would turn the headset off and potentially damage the equipment. For the sake of conducting experiments, this is

not necessarily the most important feature as this only will apply to projects Scenes that are deployed. If this is not essential for the experiment, the scene can be launched directly from the game engine, thus with a cord. The HMD is equipped with four wide-angle cameras, which enable six DoF and a passthrough option. These passthrough cameras are another pro with the Oculus Quest and are essential for the guardian function. It warns the user when they are approaching a real-world object. This allows the user to draw a boundary area in which they can move freely without interfering with real-world objects.

2.3.4 Disadvantages

Despite Oculus Quest being mobile and cordless, this also brings the biggest disadvantage. The hardware lacks the power to rival a proper gaming PC. It is, therefore, a slower system, which yields worse performance than a computer-assisted device. This could make for a bad user experience, which might cause the user to lose interest in the VE [28]. In addition, even though it is possible to screen share from the glasses, there is some delay in the viewing. This makes it harder for other persons to follow the person using the glasses. This could also impact results when using the Oculus Quest for wayfinding experiments in VR. According to Jurkic [28], the fact that AA batteries power the controllers also bring some unnecessary hassle as you need to change them every time they run out of power. A better solution could be micro USB or USB C charging capabilities. Another known issue about all types of VR headsets is that they are prone to cause motion sickness. This is previously discussed in section 2.2.5. Even though it is not an issue exclusive to the Oculus Quest, it is still a drawback that can cause users to lose interest in the VE. From a research perspective, this could cause interruptions in an experiment and further yield worse results.

Chapter 3

Experiment

As this thesis intends to use VR glasses to look into how shadow can affect wayfinding, an experiment had to be conducted to obtain results that could answer the research questions from the introduction. The following section describes the process of developing the VE and designing the experiment.

3.1 Creating the Virtual Environment

To be able to conduct an experiment in VR, a VE was made. As the thesis author wrote in her project work [6], one needs three things to develop a VE: a VR headset, a game engine, and a software development kit (SDK).

VR headset
For this thesis, the author will be using Meta's Oculus Quest. More about this particular headset is previously described in section 2.3.

Game engine
The author explored several options for choosing the game engine, such as Unity [60] and Unreal Engine [15]. Given the limitation of time for the thesis and the author's previous experience with Unity from her project work, this became the most obvious choice. According to Valem [63], Unity is also the preferred platform for creating VR experiences that can be released onto various VR devices. It is flexible, has a lot of documentation, and has a large community [63]. Even though

it is most famous for game development, it can be helpful for many other sectors as well [10]. In Unity, it is possible to develop both by modeling and using scripts or to use a combination of both. The scripting language for the platform is C#, pronounced C sharp. This helps modify the unity prefabs' logic and implement additional functionality. Unity can create several 3D objects for modeling, such as Cubes, Spheres, and planes. These can be altered without code, only by adjusting the position, rotation, scale, and material [6].

Software Development Kit

The SDK is the final step for creating a VE. This collection of tools allows the developer to create a custom app that can be added to or connected to another software. SDKs enable programmers to develop apps for specific platforms. SDKs include Steam VR and Oculus integration, which are excellent plugins. However, they rely on the headset, which implies that the VE created will not operate on other headsets. Unity addressed this issue in late 2019 by releasing its own plugin, the XR Interaction Toolkit, which merges all platforms into a single location. XR is an abbreviation for "mixed reality," which is the combination of VR and AR. This means that all of the components in this package may be applied for both VR and AR. The XR Interaction Toolkit allows creators to integrate interactivity to AR & VR experiences across supported platforms without developing interactions from scratch [17]. The XR Interaction Toolkit is the most adaptable SDK at this moment, and because it is Unity's own solution, it should last a long time. The XR interaction toolkit progressed from a preview package to a release package within the time frame of this thesis. However, only the preview package was available when the author became acquainted with using this SDK in her project work at the end of 2021. As a result, the decision was made not to use the most recent version of the XR Interaction Toolkit.

The movement within the VE is something to consider while designing it. In VE, there are three types of motion: continuous, teleportation, and natural. Since the VE in the experiment will not be released, the HMD must be connected to a computer using a cable. Due to this, the area of movement is limited by the length of the cable. Therefore, the only possibilities for movements are continuous

movement and teleportation. The option that closest resembles moving in the actual world is continuous movement. It is defined as "A type of locomotion that smoothly moves the rig by an amount over time" [59]. On the other side, it is highly likely to create motion sickness since one's eyes perceive movement, but the body does not. The most popular approach to fix this, make it slightly better, and perhaps decrease the amount of dizziness is to use the teleportation option instead. Teleportation is defined as "A type of locomotion that teleport the rig from one position to another position" [59]. Natural moving is when one moves in the real-world to move in the VE. Even though teleportation may be more convenient for participants, the author wishes to simulate the reality/authenticity of walking in the real-world as much as possible. As a result, the decision to use continuous movement was made [11].

Another challenge when creating a VE is that the different elements have to interact with each other. For instance, one would have to be able to walk on a surface that is supposed to be the ground without falling. In addition, if one wants a realistic feeling of how it is to be walking in the real-world, one should not be able to walk through buildings. This is fixed by using Unity's components called "Colliders". These components make it possible for the elements to detect collisions between objects. Using this, one can choose how different elements interact with each other. For this experiment, the properties given to objects in VE were:

- Mesh Collider: With the mesh collider, one can match the shape of the Collider to the building objects. This makes the collisions more precise and authentic. One is able to walk to the buildings, but never through [61].

- Character Controller: With Character Controller added to XR Origin, the player can move according to the environment. The Character Controller does not respond or use physics in any way. This made it possible to detect collision between the person in the VE and the mesh collider component of the buildings and ground [27].

3.1.1 Choice of Model Environment

Since the objective of this thesis is to study how shadows affect navigation, one essential part of the experiment was to select a realistic replica of the building construction and placement in the VE. First of all, a decision had to be made whether the area used for the experiment should be fictional or realistic. Making a fictional area with enough buildings with a realistic relative height and relative to the roads between would be a lot more time-consuming and inefficient. On the other hand, this would allow the possibility of making an area entirely unfamiliar for participants. On the other hand, if one were to create a realistic Scene by obtaining 3D models from the real world, there would be a risk of people being familiar with the area. In addition, one would have to find a suitable area. To use this approach, one would like to fulfill a set of criteria. These were as follows:

1. Unknown area for the participants

2. 3D building models available

3. Different heights on the buildings to make sure there were different shadows cast

4. Quadrant-based, grid-planned streets

5. Minimal elevation differences

6. Large enough area

For the first criteria, use a smaller city or area or an area outside the country so that the likelihood of people being familiar would decrease. For the second one, the author researched what options were available. After reading a previous master's thesis, [40], the author found that using the 3D application 3D Clip & Ship [18] would be a good option for extracting 3D models. Further, the program CityEngine [2] could convert the files to a filetype compatible with Unity .fbx or .obj, and then the models could be uploaded to Unity. Unfortunately, there are only 3D models from areas in Norway that are available using this software, so therefore the author had to find a suitable area within the country. The area Lillestrøm was chosen due to its relatively flat area, somewhat grid-planned

streets, and a large enough area.

After trying this approach, the author ran into a lot of technical issues. Due to the lack of time and experience using the software, the author had to find an alternative. After some research, the software Blender was found. This software also made it possible to choose an area from the entire world. Therefore, the choice to switch from Lillestrøm to New York was made. New York is quadrant-based, quite flat and the height of the buildings differs a lot.

3.1.2   Modeling Environment

Since this thesis' aim is to look at the effect shadows can have on wayfinding performance, it was essential to create a suitable environment for the experiment. Therefore, buildings had to be modeled to simulate the feeling of walking in a city, and lighting and shadows had to be implemented.

As mentioned in section 3.1.1, Blender would be the software used for modeling the buildings. Blender is a free and open-source software that may be used for almost any aspect of 3D development. Blender's features include, to mention a few, 3D modeling, texturing, animation, and video editing [23]. BlenderGIS, a Blender add-on, was used to create building models. This add-on was imported into Blender after being obtained from Github [5]. This plugin allows one to import satellite data, displacement maps, and geometry such as buildings. With this plugin, one may immediately choose the required region in Blender. This was accomplished by importing a Google satellite basemap, locating the desired location, then cropping the map to fit. Following that, the elevation for the specified region may be obtained. The author did not think adding elevation to the model for this experiment was essential since she wanted to keep the city model as simple as possible to focus on the shadows. Afterward, one may input the geometry from Open Street Map (OSM) they want to import. Only the structures were of relevance in this situation. The choice was also taken to import each building as a single object. This would make it easier to remove some buildings or make changes to the individual buildings while designing the paths if desired. Figure 3.1 depicts the application after the selected area of the map was

clipped and the geometry retrieved.
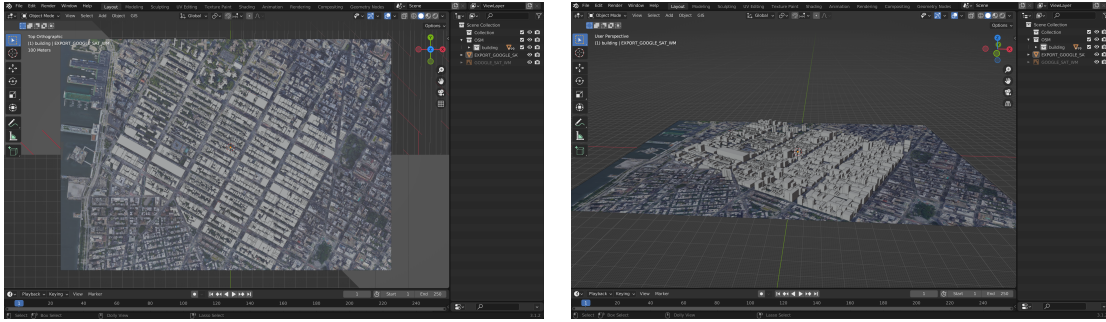
Figure 3.1: View of imported 3D models in Blender

There are two main options when making 3D models in Blender and importing them to Unity. One can import a .blend file or a .fbx file, both supported by Unity. In this thesis the choice landed on the .fbx file since the file consisted of several objects [43]. The results after importing the models into Unity can be found in figure 3.2.

Figure 3.2: Screenshot of the city model in Unity

As this thesis aims to explore how shadows, or the lack of them, could affect navigation, it was essential to create different versions of the city model: one with shadows and one without shadows. The author has previous experience with

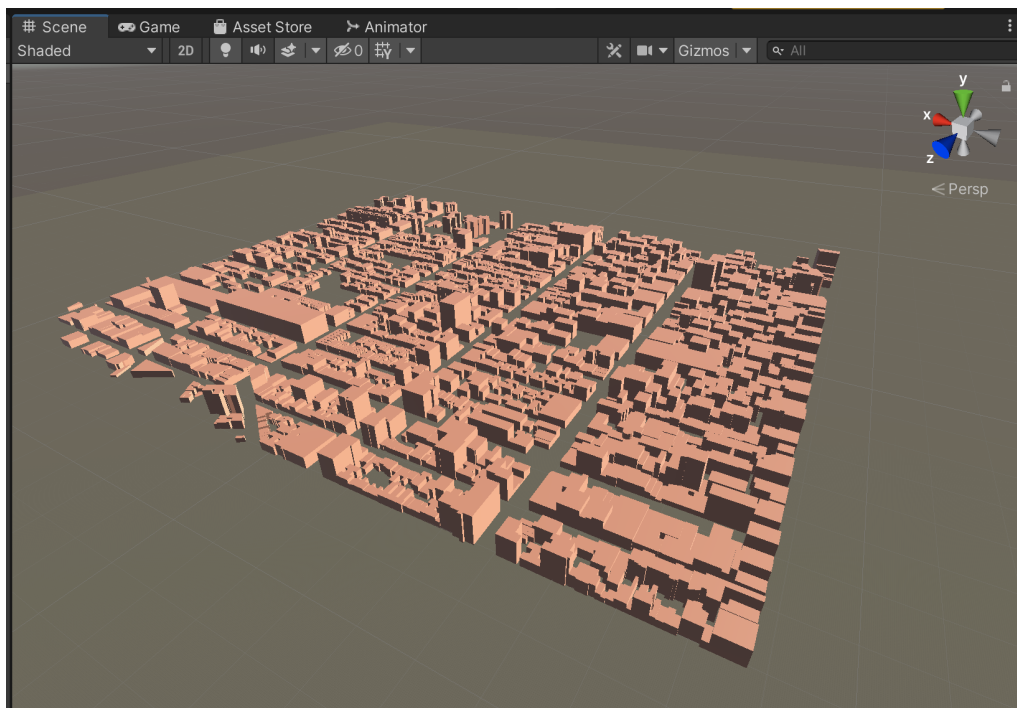looking at shadows in Unity from her project thesis [6]. Given this experiment, the choice was made to use Directional light in the VE. Technologies [62] describes directional light as "A light that is located infinitely far away and emits light in one direction only. Creates an effect of sunlight in a Scene, therefore adding convincing shading to objects without exactly specifying where the light is coming from". Figure 3.3 illustrates how the directional light looks in Unity.
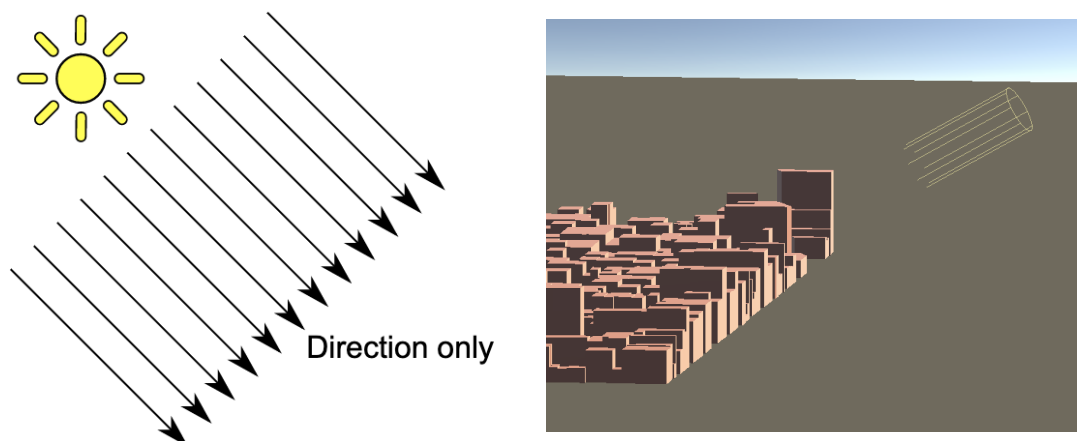
Figure 3.3: Example of directional light in Unity

The directional light causes shadows from elements, which comes in handy when creating a VE for the research purposes of this experiment. Unity also provides functions that make it possible to alter the shadows. One of the functions is that a developer can turn off assets' shadows by setting "Cast Shadows" to on or off. This is shown in figure 3.4. Figure 3.5 demonstrates what it looks like with shadows turned on and off, respectively.
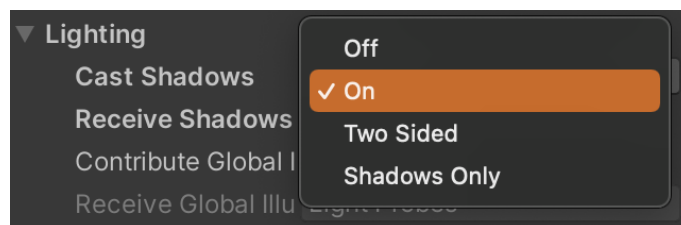
Figure 3.4: How to turn shadows on and off
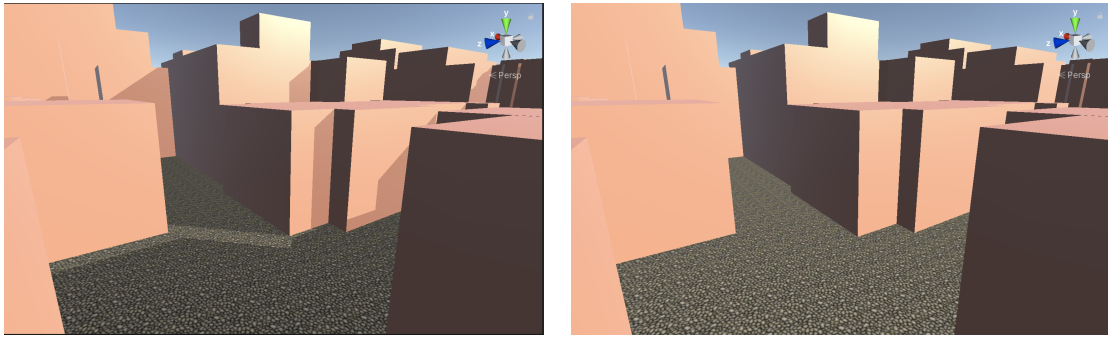
Figure 3.5: Example of the function "Cast Shadows" on (left) and off (right).

Another functionality is the option of adjusting the strength of the shadow by using a slider. This slider is illustrated in figure 3.6. For this experiment, the shadow was set to 0.5.
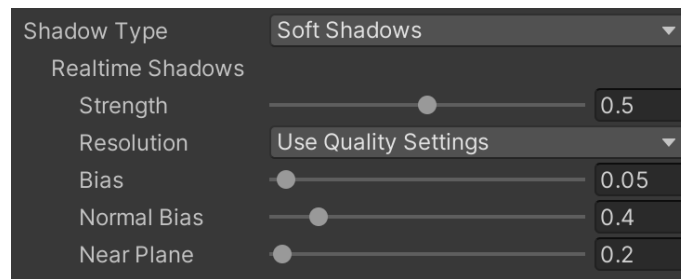
Figure 3.6: Shadow edits in Unity

3.2 Experimental Design

When conducting the experiment for this master's thesis, it was essential to ensure that it answered the research questions from the introduction. This could be done by collecting quantitative results, which can be further used in a statistical analysis. Therefore, to be certain that the experiment was designed to give adequate results, the questions listed below had to be answered:

- What is the goal of the experiment?

- How should the experiment be conducted?

- Which metrics should be measured in the experiment?

- Which statistical methods should be included?

The answers to these questions will be presented in the following subsections.

3.2.1 Methodology

Before being able to conduct an experiment, the experiment had to be designed. There are several different approaches possible, and before making a decision, these were explored. One possible approach was to create a map inside the VE, give the participants instructions to find a destination, and use the map to assist them. This could have been a nice approach. However, creating such a map would be pretty time-consuming, given that the author is not too familiar with VR development. Another approach was to talk the participants through the streets. However, when a test round was run, it was discovered that the screen sharing function slightly delayed what the participants did, which could cause some confusion when given instructions during the runs. Therefore, this method was not used in the experiment, to minimize possible errors in the results. In the end, the participants were instructed to follow arrows inside the VE to guide them from a starting point to an endpoint, after which they were asked to point in the direction of their starting point.

Plan

A plan was made to ensure the validation of the results and that the participants have the same order in the experiment.

1. Participants were asked to fill out a questionnaire about spatial abilities before arriving at the experiment. The questionnaire can be found in Appendix A.

2. Participants were informed about the goal of the experiment. They were told that the purpose was to use VR as an aid to look at how different variables could affect wayfinding.

3. Participants were informed about the possibilities of motion sickness when wearing the headset. They were instructed on factors that may cause the sickness to worsen and how avoiding this could make the experience more comfortable. Participants were informed that if it got too bad, it was possible to take a break or cancel the whole experiment.

4. Participants received an introduction and training in using Oculus Quest and navigating through the VE. HMD was adjusted to fit the participants' heads, and a demonstration of how to use the joysticks was provided.

5. Participants will get a detailed description of the experiment verbally.

6. Participants conduct the experiment and answer various questions from the researcher at the end of each attempt.

7. Participants answer the questions about how motion sickness affected the experiment.

8. Participants fill out a questionnaire about presence. The questionnaire can be found in Appendix B.

Tasks

There were made two different paths, called 1 and 2. The area of the city model was big enough so that the two paths could be made without overlapping to avoid the participants intersecting with the other path. The different paths are shown in figure 3.7

Figure 3.7: Illustration of the two paths

The paths were built differently when it comes to both length and turns. Therefore, the number of turns for each path is summarized in table 3.1.

Turns

	Path 1	Path 2
Left	11	7
Right	10	6
Total	21	13

Table 3.1: Number of turns for each path

Each path was again divided into two versions, where one had shadow and one did not, called a and b respectively. With that, there were a total of 4 different paths; 1a, 1b, 2a, and 2b. Each participant was supposed to walk two different paths, one with shadows and one without shadows. The researcher divided the group in half, where half the participants got to navigate through the non-shadow path first and vice versa. In addition, to avoid the results being affected by the participant's familiarity with the path if they were to walk the same route twice, the combination of routes always consisted of one path 1 and one path 2. This made the possible combinations for paths for the experiment a total of four, whit five participants for each combination. The combinations are illustrated in figure 3.8.

Second route

	1a	1b	2a	2b
1a				
1b				
2a				
2b				

First route

Figure 3.8: The different combinations of paths

Before beginning the experiment, the participants were verbally given the task instructions. They were told that when they put on the VR headset, they would see a green ball next to them. This green ball would represent the starting point of the path. There would also be arrows visible from the starting point, illustrated in figure 3.9.

These arrows would guide the participants to a red ball, representing the end of the path. They were told that when they arrived at the end of the path, the researcher would ask them to use the hand controllers to point to the direction they started, aka the direction of the green ball. They were instructed to try and not focus too much on the arrows but instead use the observations and surroundings to help them find the right direction.

3.2.2 Questionnaires

To be able to obtain quantitative data, surveys are often used. According to [29], a survey is a research that aims to collect and analyze data on a particular topic from a defined sample population. Questionnaires are usually used to generate
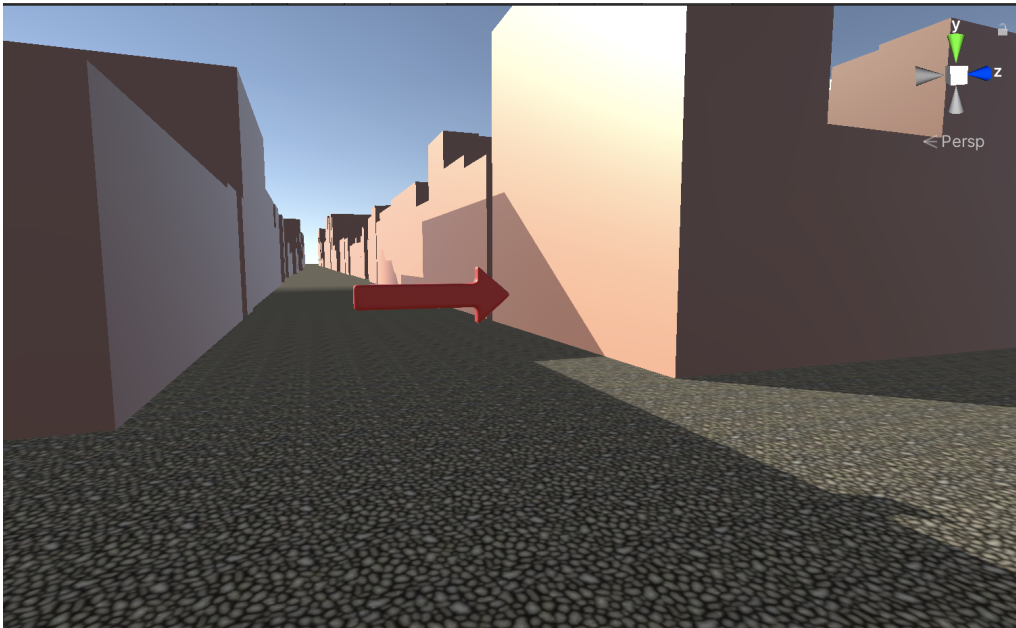
Figure 3.9: Guiding arrows

data that can be used to calculate statistical information. The questionnaires used in this thesis are described below.

Spatial Abilities Questionnaire

When conducting a wayfinding experiment such as this, one essential aspect to consider is how skilled the participants are in navigation, also known as their spatial abilities. This is important for the researcher as it would indicate whether or not it is the participant's navigational skills or the task environment that caused a fast completion time. To be able to measure the different spatial abilities of people, there are several aspects to consider. Hegarty et al. [24] therefore proposed a method that uses a self-report scale called the Santa Barbara Sense of Direction scale (SBSOD). Something to keep in mind is that the SBSOD is reported to have a better effect when the tasks consist of self-motion and orienting oneself in the environment. As this experiment contains arrows that guide the participants through the environment, this could lead to the effect being somewhat smaller. The questionnaire consists of 15 statements, scaled from 1 (strongly agree) to 7 (strongly disagree), which makes the average score 4. When calculating the results, it is recommended to reverse score the positively phrased statements. This results in a low score indicating less ability and a high score indicating more

ability. After doing this, one can compute the overall score by taking the total score of all statements and dividing it with the number of statements. This will give a number between 1 to 7, where the higher the score, the better the spatial abilities. The questionnaire can be found in appendix A.

Presence Questionnaire

For experiments conducted in a VE, it is valuable to understand how the participants felt while inside the VE and if this could have an impact on the performance in the experiment. For instance, if most participants felt a lack of presence, this might indicate that the VE was poorly simulated and could lead to a loss of interest resulting in worse performance. Therefore, the participants were asked to complete a presence questionnaire created by Slater et al. [54] after conducting the experiment. The VE was created without completely considering realism in order to highlight navigation using only buildings and shadows as help. Accordingly, the findings of the results cannot be looked at conclusively. However, it may indicate whether or not the participant felt immersed in the environment. The questionnaire consists of five questions, scaled from 1 to 7. The questionnaire can be found in appendix B.

Motion Sickness

Since motion sickness is a known issue when using VR glasses, which the author experienced first hand while creating the city model and experiment, the participants were questioned about how they were affected by this during the experiment. This was to map how this factor could affect the results of the experience, for instance, if someone had to abort the experiment because of sickness.

3.3 Execution

The experiment was divided into two parts. First, a pilot test was conducted to detect flaws in the plan. After that, a full experiment with more participants was conducted.

Pilot test

Before the experiment, a pilot test was performed to get feedback on VE and test the plan for the experiment. According to Kitchin and Tate [29], a pilot study will indicate whether your research approach is suitable, if you will acquire access to respondents and how long the entire research project is expected to take. Without a pilot study, projects frequently encounter challenges that are difficult to solve without scrapping what has been collected so far and starting over. There were four participants in the pilot test, two males and two females, with an average age of 23.5 years. The participants followed the plan described in section 3.2.1. As this was a pilot test to gain experience from the experiment before conducting the real experiment, the participants were in addition to these steps, also asked to give feedback on the execution and environment of the experiment. From these tests, several things needed to be taken into consideration. Some of these are listed in table 3.2.

Feedback	Improvements
The walking was a little bit slow.	Turned up the walking speed from X to X.
The arrows on the wall were a little hard to see, and sometimes they flicker. It would be nice if there were another option.	Switched from 2D arrows on walls to 3D arrows "floating in the air" along the paths.
I was very affected by motion sickness. Is there some way to make this feel better?	Found some tips that could help with feeling less motion sickness during the experiment. The participants were also given even more descriptions
The shadows could be a little bit more powerful.	The strength of the shadows was initially set to 0.5. The strength to increase it to 1, but this was too much. Therefore, the shadows were changed to 0.75 for the final experiment.
Felt that the body rig was a little bit too big compared to the buildings in the environment.	The XR Rig was scaled down.
The time consumption of the paths should be shorter. Increasing speed would do some effect, but the paths should also be a little bit shorter.	This was done by decreasing the number of turns and distance between turns.
I was given too little information about the purpose of the experiment and how it was supposed to be conducted.	Gave a more thorough description of the experiment's goal, purpose, and tasks at the beginning. The participants were instructed on how the experiment would take place, and how different variables would be measured but not which variables. This was to not influence their choices.
There was a big difference in lighting. It seemed more like night and day than with and without shadow. This resulted in not paying much attention to the shadows.	The author made sure the directional light was the same for both paths, only turning off the shadows.

Table 3.2: Feedback from participants of the pilot test

Participants

The experiment consisted of 20 participants, 10 female and 10 male. Their ages ranged from 19 to 25 years, with an average age of 22 years. All the participants were students at the Norwegian University of Science and Technology (NTNU). The participants were not familiar with the area.

To be able to run the Unity scene, the Oculus Quest was connected to a computer by a cable. This was specified to the participants so that they would remember not to move too much around, as this could lead to the loss of connection if they unplugged the cable or even drag the computer down from the desk. The screen was casted and shared to the computer to see what the participants were doing while conducting the experiment within the VR glasses. The experiment lasted about 20-25 minutes on the occasions it ran without any technical issues. Figure 3.10 depicts one participant conducting the experiment in a classroom at the university.
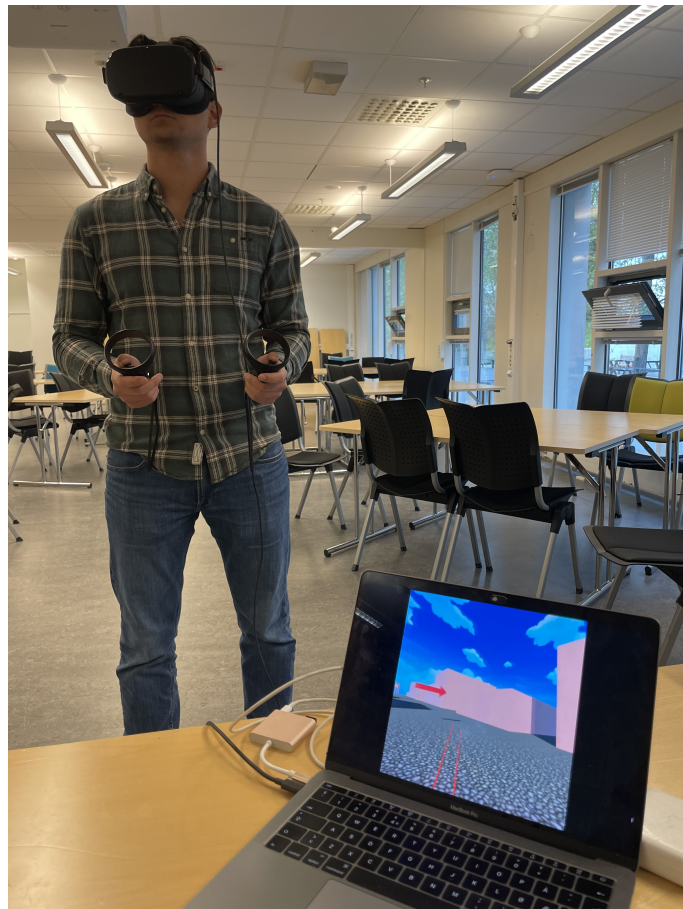

Figure 3.10: Picture of one of the participants conducting the experiment

Chapter 4

Results

In this section, the results of the experiment will be presented. It will summarize the gathered data and present the statistical theory which will then be applied to the gathered data. The analyses were calculated in either Minitabs [36] or Microsoft Excel [35]. In addition, the results from the different questionnaires will be summarized and presented.

4.1 Results Gathered

All the results gathered from the experiment are shown in Appendix C. For each participant, it was registered which direction they pointed to and drawn a line from the endpoint and to what they believed was the starting point. As the experiment consisted of four different combinations of order for two attempts each, previously illustrated in figure 3.8, it would be too few observations to have any statistics calculated. Therefore, the observations have been merged into "shadows" and "no shadows", for both path 1 and path 2. This makes a total total of ten observations for each picture. Figures of the Scenes containing the results from each of these are illustrated in figures 4.1 and 4.2. The green line indicated the correct direction line from the endpoint to the starting point.
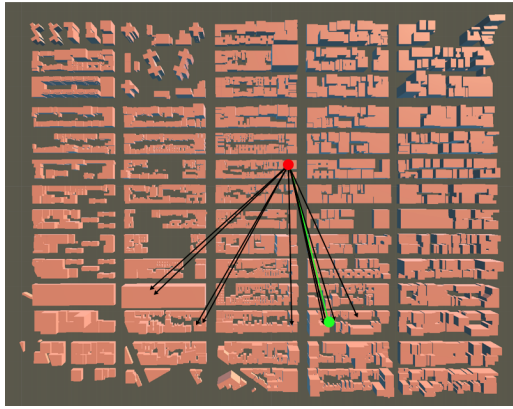
(a) Path 1a
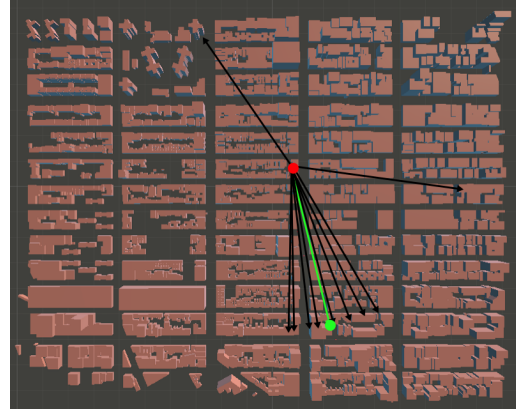
(b) Path 1b

Figure 4.1: Results of path 1
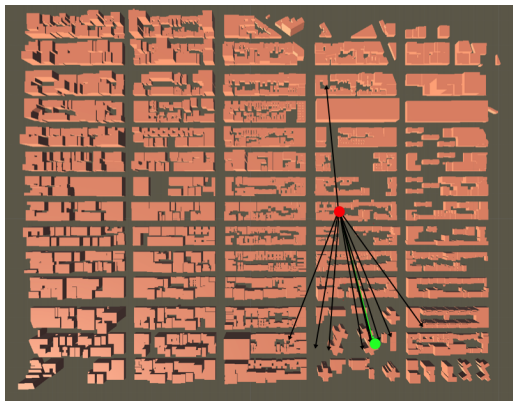
(a) Path 2a
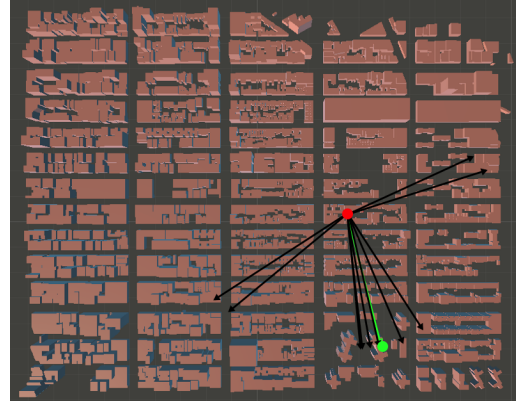
(b) Path 2b

Figure 4.2: Results of path 2

After the lines were drawn into the figure, the angle between the correct answer and each result was calculated to find the number of degrees deviated from the correct direction line. During the experiment, there were comments about one path being shorter and easier than the other, as well as it being easier to think back for the second attempt since the participants already had been through one. Because of this, the choice was made to look at three different factors. These are as followed:

- The difference between paths with shadows and wihtout shadows

- The difference between path 1 and path 2

- The difference between the path walked first and the path walked last

The results from the different factors are listed in table 4.1, 4.2 and 4.3.

	Shadows	No shadows
Number of observations	20	20
Mean x (degrees)	5.1	-1.4
Minimum (degrees)	-171	-100
Maximum (degrees)	63	161
Standard deviation of x (degrees)	47.8	53.9

Table 4.1: Results for shadow vs. no shadows

	Path 1	Path 2
Number of observations	20	20
Mean x (degrees)	15.4	-11.7
Minimum (degrees)	-68	-171
Maximum (degrees)	161	65
Standard deviation of x (degrees)	45.1	52.8

Table 4.2: Results for path 1 vs path 2

	First path	Second path
Number of observations	20	20
Mean x (degrees)	-5	8.75
Minimum (degrees)	-171	-68
Maximum (degrees)	161	65
Standard deviation of x (degrees)	64.2	31.39

Table 4.3: Results for first and last path

4.2 Statistics Theory

In this section, the statistics used in this thesis will be explained. We will be looking at hypothesis testing to determine whether the results are significant or not and performing normality tests to determine which of the significance tests can be used. In addition, the correlation between results and the participants' spatial abilities and level of presence was calculated to see if this affected the wayfinding performance.

4.2.1 Normal Testing

The first stage in the statistical analysis is determining the probability distribution the data sets may match. The sampling distribution is determined by the population distribution, sample size, and sample selection procedure. The sampling distribution describes the variability of sample averages around the population mean, μ. In statistics, parametric tests are preferred because they have more statistical power than non-parametric tests. The power of a test is the likelihood of successfully rejecting a false null hypothesis, which in this case is the capacity to identify if the samples originate from a non-normal distribution. All parametric statistics are based on the assumption of normally distributed independent observations. When attempting to determine a normal distribution, both visual methods and normality tests can be used to evaluate this [14]. For visual inspections, histograms can be used. Normality tests compare the scores in the sample to a normally distributed set of scores with the same mean and standard deviation. A normality test had to be selected to further evaluate and validate that the data matched a normal distribution [19]. The choice of normality tests will be presented in the following sections.

Anderson-Darling

After exploring several tests, such as D'agostino-Pearson and Shapiro-Wilk, the Anderson-Darling test was chosen. The Anderson-Darling test is commonly used to determine if a data set fits a particular distribution, such as the normal distribution, which we are interested in here. When testing for normality, all

Anderson-Darling tests in this thesis are performed with a confidence interval of 95%. The estimated p-value is compared to the chosen significance level when determining whether to reject or accept the null hypothesis (0.05 for a 95% confidence interval). We shall retain the null hypothesis if the p-value is greater than 0.05, and it will be rejected otherwise [34]. The Anderson-Darling test hypotheses are as follows [39]:

$$H_0 : \text{The data follows the normal distribution}$$

$$H_1 : \text{The data does not follow the normal distribution}$$

If the null hypothesis is rejected, a transformation is typically used to make the data appear to more closely meet the assumptions of a normal distribution. This is often achieved by employing a non-linear transform like square root, logarithmic, or inverse (1/x) [29]. We will use the Logarithmic transformation with a base of 10 in this thesis. Because the logarithm is invertible, all outcomes may be translated back to their original values using the function $f(x) = 10^x$, where x is the value to be transformed back [52].

4.2.2   Hypothesis Testing

The following stage in the analysis is choosing a suitable statistical approach. Many statistical procedures are commonly referred to as significance (or hypothesis) tests because they investigate the extent to which a hypothesis may be significant [29]. The null- and alternative hypotheses are statements about a difference or effect in the study's population. The alternative hypothesis H_1 generally symbolizes the question to be answered or the theory to be investigated, whereas the null hypothesis H_0 negates or contradicts H_1. The study's sample is used to determine which assertion is more likely [66].

Two-sample t-test

When we have parametric data with two groups, we can use a two-sample t-test to determine if the differences in the means are significant [29]. The hypotheses for

the two-sample t-test for unpaired data are [37]:

$$H_0 : \mu_A = \mu_B$$

$$H_1 : \mu_A \neq \mu_B$$

In a two-sample, two-sided, t-test the null hypothesis is rejected if [66]:

$$|T| > t_{1-\alpha/2,v} \tag{4.1}$$

T is the calculated statistical value, and t is the critical value with the specified significance level (α) and degree of freedom (v). The critical value may be found in the Critical values for the t-distribution table.

Bartlett's test

In addition to assuming normal distribution, it is valuable to know whether the samples are from populations with equal variances when using the two-sample t-test. To check this, we can use the Bartlett's test. It tests the hypothesis [56]:

$$H_0 : \sigma_1^2 = \sigma_2^2 = ... = \sigma_k^2$$

$$H_A : \sigma_i^2 \neq \sigma_j^2 \text{ for at least one pair (i,j)}$$

Mann-Whitney U test

Even after transformation, the data may sometimes not fit into a normal distribution. Several alternative tests may be used in this scenario. The Mann-Whitney U test is one of them. This is a non-parametric test that compares differences between two independent groups. It may be used on samples that are not normally distributed since it is non-parametric. Unlike the t-test, it compares the median scores of two samples rather than the mean score. It ranks the data independent of the group and compares the two groups' sums. If the total of the rankings between the groups is about equal, the null hypothesis is accepted; otherwise, it is rejected. The Mann-Whitney U test hypotheses are as follows [38]:

$$H_0 : \mathrm{median}_A = \mathrm{median}_B$$

$$H_1 : \mathrm{median}_A \neq \mathrm{median}_B$$

The Mann-Whitney U test assumes that the variances and distributions of the samples are equal. As a result, a preliminary check must be performed to establish equal variances before performing the test. We will apply Levene's test to this. Levene's test is similar to Bartlett's test, except it does not assume a normal distribution. The hypotheses for the Levene's test are identical to those for Bartlett's test [57]:

$$H_0 : \sigma_1^2 = \sigma_2^2 = ... = \sigma_k^2$$

$$H_A : \sigma_i^2 \neq \sigma_j^2 \text{ for at least one pair (i,j)}$$

If a data set does not meet the assumption of equal variances, the Mann-Whitney U test can still be used since it is regarded as more robust than the two-sample t-test in its current form [12].

4.2.3   Correlation

To see if there are any connection between different data sets, the correlation can be calculated. The correlation coefficients are indicators of the strength of the linear relationship between two different variables. The correlation coefficient calculated is a number between -1 and 1. If the coefficient is greater than zero, it indicates a positive relationship. A value that is less than zero signifies a negative relationship. Finally, a value of zero indicates no relationship between the two variables [44]. To check if the correlation coefficient for two data sets is significant compared to each other, one can calculate the p-value. If the P-value is greater than the significance level of 0.05, the results are not significant [69].

4.3   Statistics Applied

This section will first present the results in histograms and test if they follow a normal distribution using the Anderson Darling test. If the results are not normally distributed, a transformation will be made. Equal variance assumptions will also be tested using Bartlett's and Levene's tests. After the assumptions for each result are tested, they are used in a hypothesis test which will lead to an answer to the research questions listed in the introduction. The results will be summarized at the end.

4.3.1   Normal Testing

To determine whether the results come from a normal distribution, a preliminary check of the results is required. To find the distribution of the results, a histogram was made. Before the histogram was made, an outlier test was made to detect any outliers in the data set and to remove these from the set.

Shadows vs. no shadows

The outlier test for shadows vs no shadows gave two outliers, one for each case. These are presented in figure 4.3.

Variable	Row	Outlier
Path with shadow	1	-171
Path without shadow	20	161

Figure 4.3: Outlier with and without shadow

After removing the outliers, a histogram was made for each of the case. The histograms are shown in figure 4.4.

(a) With shadows without outliers   (b) Without shadows and outliers
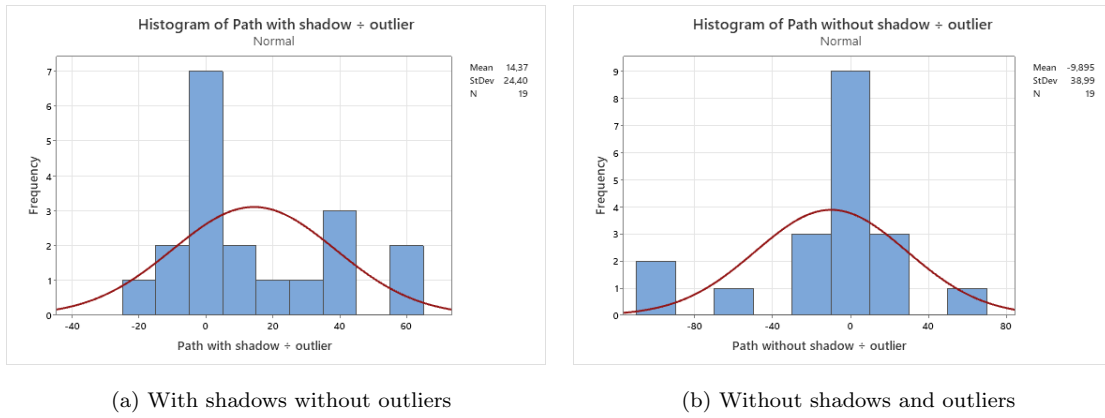
Figure 4.4: Results with and without shadows and outliers

It is difficult to say anything about the distribution through visual inspection. Therefore, the Anderson-Darling test was applied to further examine if the data fits a normal distribution. The results are illustrated in figure 4.5.

(a) With shadows without outliers   (b) Without shadows and outliers

Figure 4.5: Results with and without shadows and outliers

As one can see, the p-values are lower than 0.05, which tells us that the data does not follow the normal distribution. This means that the data needs to be transformed before it can be used in either of the hypothesis tests. Figure 4.6 shows a histogram of the values transformed.

(a) With shadows transformed   (b) Without shadows transformed
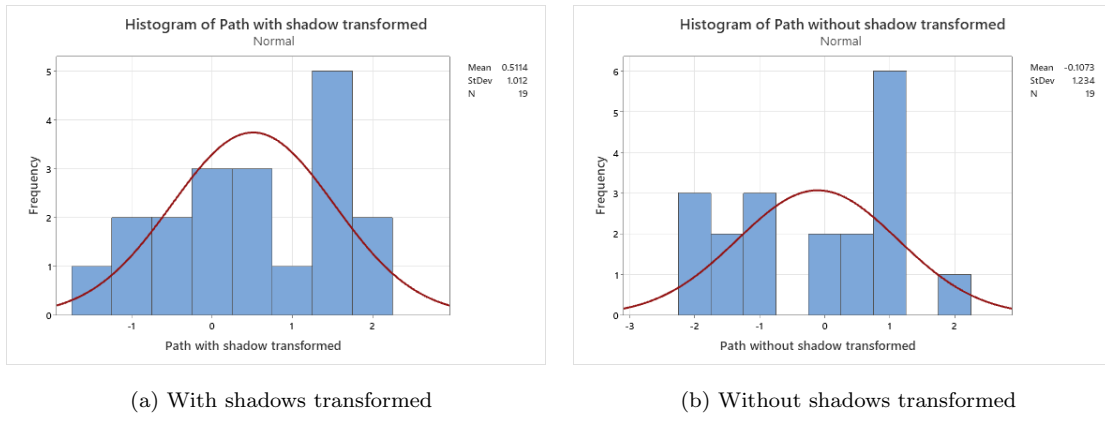
Figure 4.6: Results with and without shadows transformed

After transforming the data set, a new Anderson-Darling test must be conducted to see whether the data is normally distributed. The results of this new test are shown in 4.7.
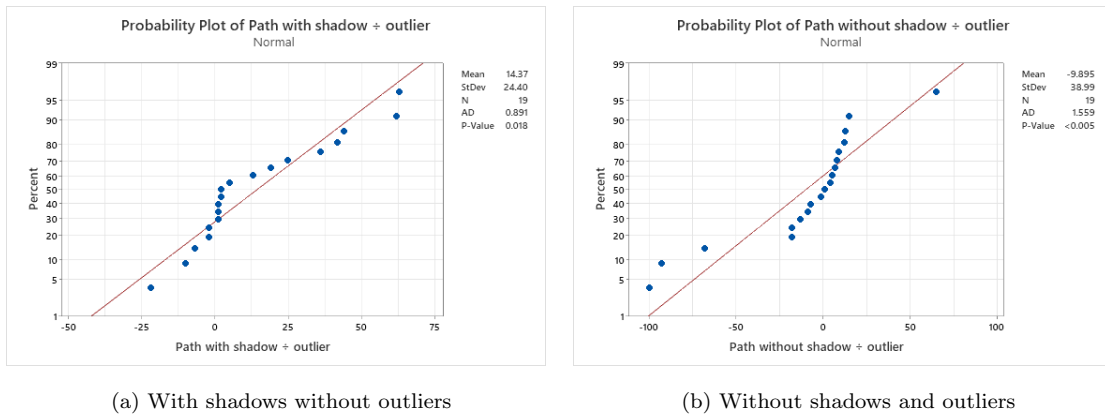

(a) With shadows transformed   (b) Without shadow transformed
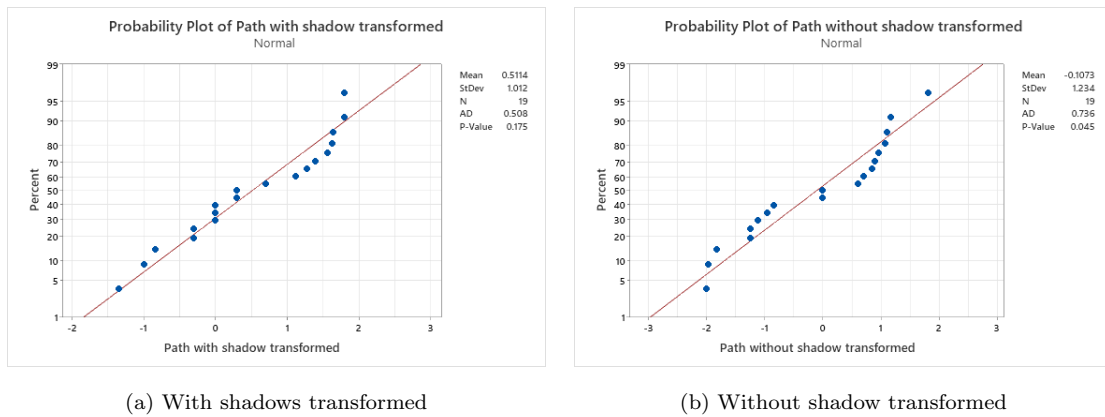
Figure 4.7: Results with and without shadows after transformation

After the new Anderson-Darling test, one can see that figure 4.7a now fits the normal distribution, while figure 4.7b still has a P-value lower than 0.05 and does not fit the normal distribution.

Path 1 vs. Path 2

The outlier test for path 1 vs. path 2 gave two outliers, one for each case. These are presented in figure 4.8.

Figure 4.8: Outlier path 1 and 2

After removing the outliers from the results, a histogram was made, illustrated in figure 4.9.

(a) Path 1   (b) Path 2
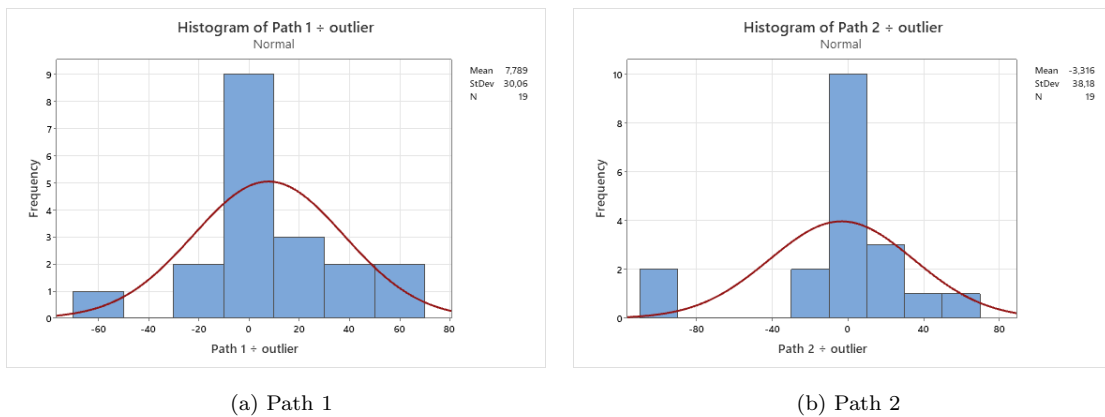
Figure 4.9: Results for path 1 and 2 without outliers

It was also not possible to see whether the data fit a normal distribution during visual inspection for these results, and the Anderson-Darling test was applied. The results are illustrated in figure 4.10.

(a) Path 1 without outlier   (b) Path 2 without outlier
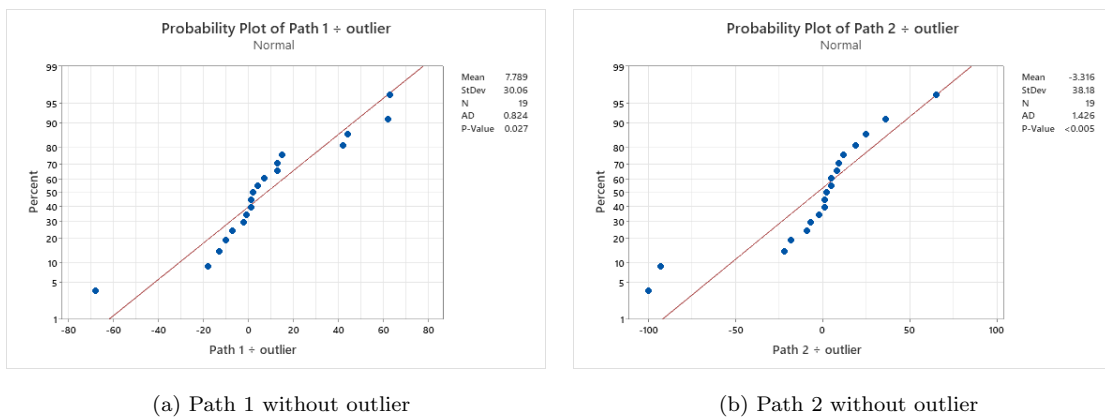
Figure 4.10: Results of Anderson-Darling test for path 1 and 2 without outliers

As one can see, the p-values are lower than 0.05, which means that these data sets too do not follow the normal distribution, and a transformation must be performed. Figure 4.11 shows a histogram of the values transformed.

(a) Path 1 transformed   (b) Path 2 transformed

Figure 4.11: Results for path 1 and 2 after transformation

After transforming the data set, a new Anderson-Darling test had to be conducted to see whether the data were normally distributed. The results of this new test are shown in 4.12.


(a) Path 1 transformed   (b) Path 2 transformed
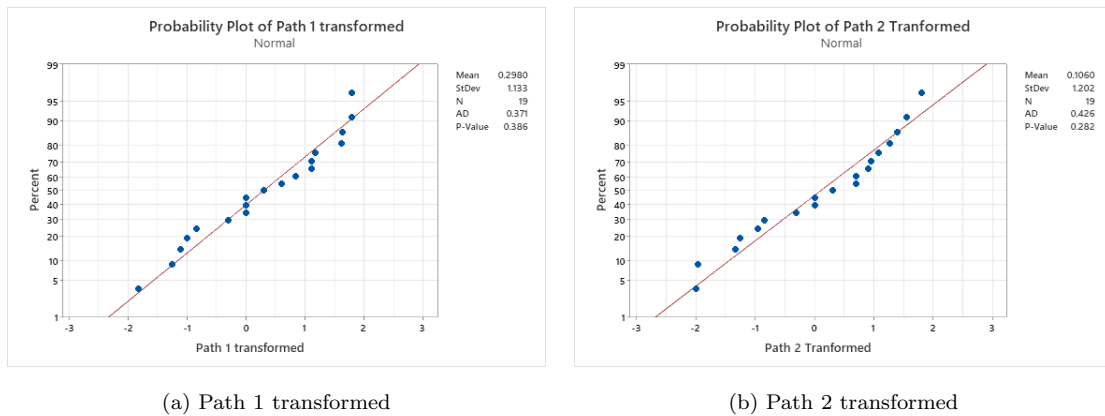
Figure 4.12: Results of Anderson-Darling test after transformation for path 1 and 2

As we can see, the p-values for both figure 4.12a and 4.12b are above the significance level of 0.05, and they are therefore normally distributed.

First path walked vs. last path walked

For the last group there were no outliers, so the histograms were made without removing any values. The histograms are presented in figure 4.13.

(a) First

(b) Last
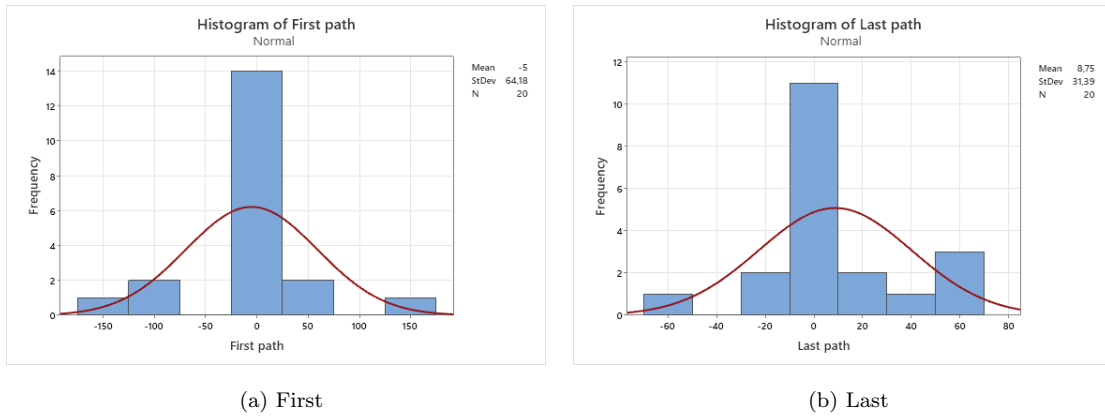
Figure 4.13: Results for path walked first and path walked last

The Anderson-Darling test was applied for these data sets, and the results are illustrated in figure 4.14.

(a) First without outlier

(b) Last without outlier
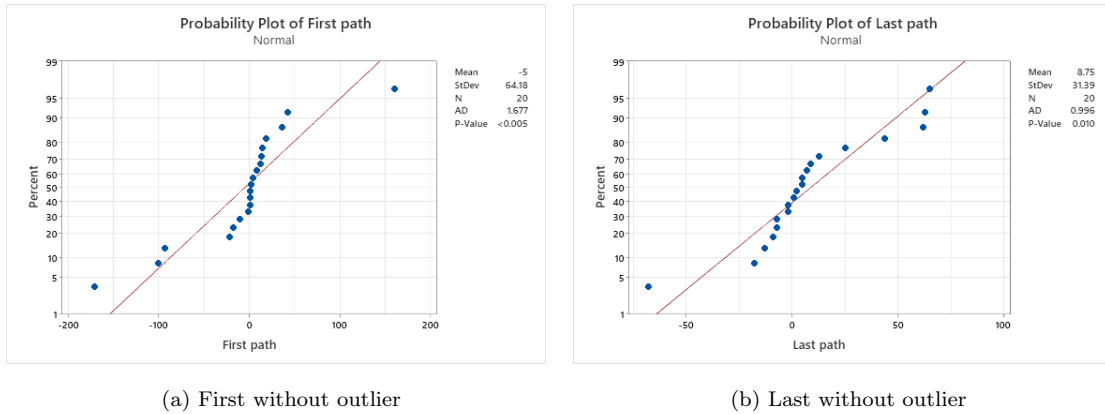
Figure 4.14: Results of Anderson-Darling test for path walked first and path walked last

The p-values are again lower than 0.05, indicating that the data sets do not follow the normal distribution, and a transformation must be made. Figure 4.15 shows a histogram of the values transformed.
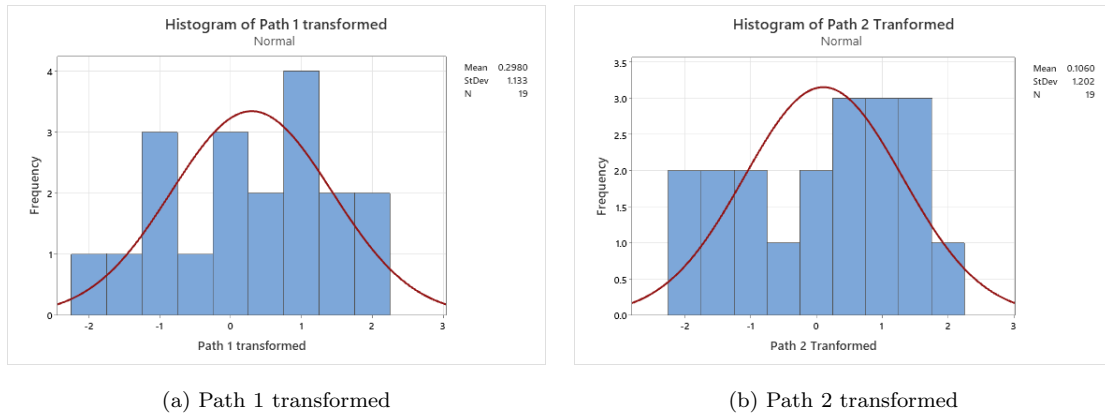
(a) First path transformed   (b) Last path transformed
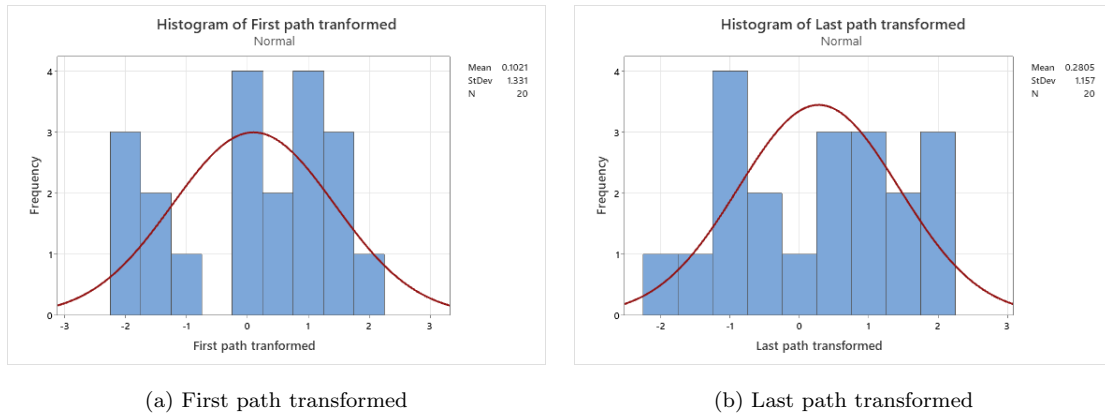
Figure 4.15: Results for first path walked and last path walked transformed

After transforming the data set, a new Anderson-Darling test had to be conducted to see whether the data were normally distributed. The results of this new test are shown in 4.16.


(a) First path transformed   (b) Last path transformed
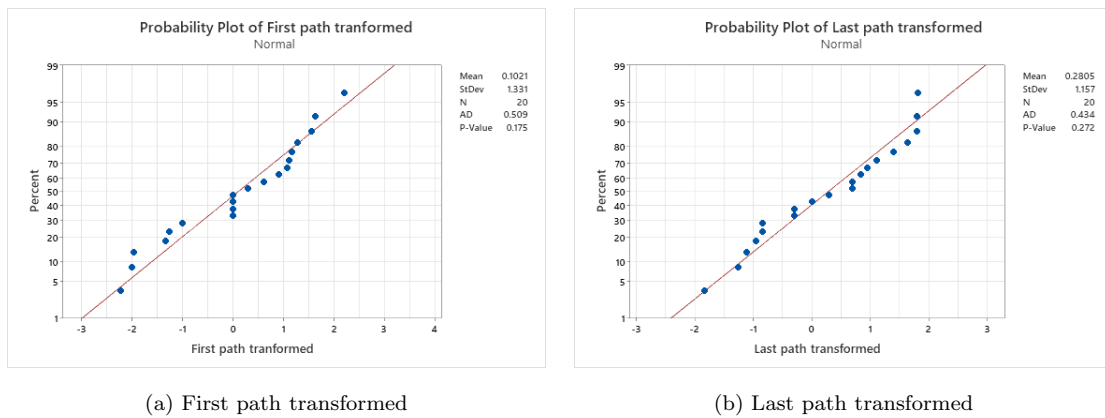
Figure 4.16: Results of Anderson-Darling test for first and last path transformed

After looking at the results, we can see that both figure 4.16a and 4.16b have a p-value above the significance level of 0.05 and therefore fits a normal distribution.

4.3.2   Hypothesis Testing

Shadows vs. no shadows

As the p-value for the path without shadows does not meet the assumption of a two-sample t-test, the Mann-Whitney U test will be used instead. Since this test assumes equal variances, the Levene test had to be conducted first. For the Levene test, we can accept a risk of 5%, which gives a significance level $\alpha = 0.05$. The

Levene test gives $p = 0.242$, which is greater than 0.05. This indicates that the variances are equal, and the Mann-Whitney U test can be implemented. When the Mann-Whitney U test is conducted, we get $p = 0.115$. This is greater than the significance level of 0.05. This indicates that there is no significant difference between the two data sets.

Path 1 vs Path 2

After the transformation, the two data sets meet the assumption for a two-sample t-test. Therefore this test will be used. Before the test is conducted, we have to check if we will run the test assuming equal variances or not. To do this, we can use the Bartlett's test. After conducting this test, we get $p = 0.40396$ which is greater than the significance level of 0.05. This indicates that the variances are equal. After this, we can conduct the two-sample t-test with this assumption. This gives us $|T| = 0.51$. To see if this indicates significance or not, we have to look at the t-table. We find that the critical value is 2.042. Since 0.51 is not greater than the critical value, we can say that there is no significant difference between the two data sets.

First path vs Last path

After the transformation, the two data sets meet the assumption for two-sample t-test. Therefore this test will be used. Before the test is conducted, we have to check if we will run the test assuming equal variances or not. To do this, we can use the Bartlett's test. After conducting this test, we get $p = 0.02642$ which is not greater than the significance level of 0.05. This indicates that the variances are unequal. After this, we can conduct the two-sample t-test assuming that the variances are unequal. This gives us $|T| = 0.45$. Again we look to the t-table and find the critical value of 2.042. Since 0.45 is not greater than the critical value, we can say there is no significant difference between the two data sets.

After the transformation, the two data sets meet the assumption for two-sample t-test, therefore this test will be used. Before the test is conducted, we have to check if we will run the test assuming equal variances or not. To do this we can use

the Bartlett's test. After conducting this test we get a p-value = 0.02642 which is not greater than the significance level = 0.05. This indicates that the variances are unequal. After this we can conduct the two-sample t-test with the assumption that the variances are unequal. This gives us a $|T| = 0.45$. Again we look to the t-table, and find the critical value of 2.042. Since 0.45 is not greater than the critical value, we can say that there is not a significant difference between the two data sets.

4.3.3 Correlation

In order to answer research question 2, if spatial abilities and level of presence affect performance in wayfinding differently in models with shadows and models without shadows, the correlation between the different data sets obtained in the experiment can be calculated. As the differences between path 1 and path 2, and the first path walked and the last path walked also have been explored, we will also look into the correlation between the SBSOD score and level of presence for these observations. The results from the statictical calculations are shown in table 4.4, 4.5 and 4.6.

	SBSOD - Mean degrees		Presence - Mean degrees	
	Correlation	P-value	Correlation	P-value
Shadows	0.05162449	0.828871187	0.182533548	0.441146656
No shadows	0.157508253	0.507201406	-0.357921218	0.121271601

Table 4.4: Correlation between SBSOD and presence for paths with and without shadows

	SBSOD - Mean degrees		Presence - Mean degrees	
	Correlation	P-value	Correlation	P-value
Path 1	0.067810328	0.776366491	-0.131527771	0.580408063
Path 2	0.141295782	0.552378078	-0.07643924	0.748737645

Table 4.5: Correlation between SBSOD and presence for path 1 and 2

	SBSOD - Mean degrees		Presence - Mean degrees	
	Correlation	P-value	Correlation	P-value
First	-0.050797516	0.831574622	0.040425554	0.865626613
Last	**0.462979999**	**0.039811102**	-0.423273055	0.062946285

Table 4.6: Correlation between SBSOD and presence for first and last path walked

What can be seen from the table is that there is a significant correlation between SBSOD and the results from the last path walked. One factor to consider is that a positive coefficient means that the higher the SBSOD and presence score, the higher the mean degree discrepancy, which is actually negative and an indication of bad performance.

4.3.4 Summary of Results

A summary of the results from the experiment is presented in table 4.7. All the results is obtained by using a confidence interval of 95%.

Question	Significant differences
Are there differences in performance for shadows vs no shadows?	No
Are there differences in performance back for path 1 vs path 2?	No
Are there differences in performance for first path vs last path?	No
Is there a correlation between SBSOD or Presence, and performance with shadows?	No
Is there a correlation between SBSOD or Presence, and performance without shadows?	No
Is there a correlation between SBSOD or Presence, and performance on path 1?	No
Is there a correlation between SBSOD or Presence, and performance on path 2?	No
Is there a correlation between SBSOD or Presence, and performance for path walked first?	No
Is there a correlation between SBSOD and performance for path walked last?	Yes
Is there a correlation between Presence and performance for path walked last?	No

Table 4.7: Summary of results

4.4   Spatial Abilities Questionnaire

Before conducting the experiment, each participant was asked to answer the spatial abilities questionnaire. This was to see whether there was a connection between the participant's spatial abilities and their performance in the experiment. As previously explained in section 3.2.2, the form results in an SBSOD score, which ranges from 1 to 7, where the higher the number, the better the spatial abilities. Before calculating the scores, one had to adjust for positively phrased statements. The lowest score, 2.95, belongs to Question 5 "I tend to think of my environment in terms of cardinal directions (N, S, E, W). The highest score, 4.9, belongs to question 1, "I am very good at giving directions ." The mean score for the questionnaire was 4.163.

4.5   Presence Questionnaire Results

From section 3.2.2 we know that the presence questionnaire consisted of 5 questions, scaled from 1 to 7. The lowest score from the presence questionnaire was 3.55 and belonged to question 5, "During the time of the experience, did you often think to yourself that you were actually in the office space?". The highest score was 5.9 and belonged to question 4, "During the time of the experience, which was strongest on the whole, your sense of being in the VE, or of being elsewhere?". The mean value for the questionnaire was 4,75. One thing pointed out during the experiment was that the questionnaire was somewhat difficult to understand. Some of the questions were quite similar and difficult to tell apart. Therefore, many participants had to ask clarifying questions to understand how to answer the questionnaire correctly. However, this was not enough, and many participants said they just chose what they thought would be right.

4.6   Qualitative Participant Data

Both during and after the experiment, the participants were asked different questions about the VE, paths, and navigational habits. Their answers are presented in the sections below.

4.6.1   Process of pointing

After the participants ended each path, they were asked to point in the direction of their starting point. After pointing, they were asked to describe their reasoning as to why they were pointing this way. There were a lot of similar answers, and they are summarized below:

- Most of the participants said they were listening to their guts about which direction they came from.

- A lot of the participants also commented on how they paid attention to how many left and right turns they made and made their decision from that.

- Some participants also said that they lost their entire sense and feeling of direction and took a wild guess on where they came from.

- Another answer that several participants gave was that they, throughout the experiment, were constantly thinking about where the green ball was in relation to oneself each turn.

4.6.2   Difference between paths

After walking through both paths, the participants were asked if they noticed any differences between the two paths. There were also comments made while the participants walked through the paths. The answers are summarized below:

- More small roads and winding streets on path 1, but also a larger main road.

- Path 1 had more turns and a longer route.

- Path 2 had greater distances between the buildings in terms of height. It had both taller and lower buildings than path 1.

4.6.3 Navigational habits

At the end of the experiment, the participants were asked about their wayfinding habits. How they usually find their way around. Most of the participants had very similar answers, and the most common answers were as follows:

- When in an unfamiliar area, all participants said that they used Google maps to find their way around.

- A lot of the participants use recognizable buildings and other landmarks to find their way back or to recognize which way they came from.

- Another thing many of the participants use are signs and their position in relation to main roads or similar constructs. For example, walking the main roads makes it easier to get a clear view and not lose track of their position.

- Several participants also mentioned that they might take a detour to walk to a familiar area because they know their way from there.

4.7 Motion Sickness Results

As mentioned in section 3.2.2 the participants were asked about motion sickness. Halfway through the experiment, after the first path, the participants were asked how they felt and if they wanted to take a break before conducting the rest of the experiment. After the participants finished the experiment, each one was asked about motion sickness, how they felt during the experiment and how it affected their ability to conduct the experiment. Some of the comments that repeated themselves were:

- Almost half of the participants said they did not notice that much motion sickness. However, most of them said that it was somewhat "weird" to use the glasses and that they might have experienced some sickness if the experiment had been longer.

- The most uncomfortable thing was to use the right-hand joystick, which had the function of turning around. This was a very unnatural feeling and made

several participants lose balance and feel dizzy and sick.

- Many of the participants that were okay but claimed they felt somewhat uncomfortable during the experiment said that the motion sickness had developed during the next hours. So even though they said it was fine after the experiment, they got more sick and dizzy during the next hours.

- Many of the participants struggled with keeping their balance, and a few even had to take a seat because they felt they were going to fall.

Chapter 5

Discussion

In this thesis, an experiment consisting of 20 participants has been conducted. The goal of the experiment was to explore whether or not the shadows on the city model affected wayfinding performance. In addition, we also wanted to see if spatial abilities and level of presence would affect the wayfinding performance differently with shadows than without. After completing the experiment, a choice was made to also look at the difference in performance between path 1 and 2, as well as when walking a path first or last. The results are summarized in table 4.7.

Looking at the shadows vs. no shadows results, no significant differences were found with a confidence interval of 95%. One theory on why this might be is that the arrows used in the city model were a bit too much of help. When asking the participants what they were thinking when pointing in the direction of origin, many replied that they counted arrows, how many arrows were left, and how many were right. The arrows were just supposed to be an aid to help guide the participants from the starting point to the end. Perhaps another guiding approach should have been used and is something to consider in the future. Another theory to approach is the amount of shadow in the VE. As mentioned in section 3.1.2, the author decided to create a realistic model environment by extracting 3D building models from OSM via Blender and the add-on BlenderGIS. This decision was made to make the process more efficient. However, when looking back at the experiment, this solution might not have been the most optimal as the author

could not entirely remove the shadows from the buildings. The author was able to remove the shadows cast from buildings and unable the buildings to receive shadows, but the walls of the buildings were still different colors whether they were located on the "sunny side" or not. Perhaps this would have been easier to solve if the author had built the 3D models, and the city model, from scratch instead. This could have affected the experiment as the difference between the two paths was not as significant when the shadow on buildings was the same in both cases.

The author noticed that the participants made more effort during the experiment's second attempt. The participants appeared to learn from the first attempt and used this to think more about how they acted in the second attempt. For example, the participants mentioned how they thought differently verbally aloud during the second attempt. It was evident that the participants sharpened their focus for the second attempt. Even though they were given instructions on what they were supposed to do in the experiment, it seemed like it took the first attempt for the participants to really understand what the instructions would mean. This is why the author wants to look at the difference between the results from the path walked first, and the path walked last. From section 4.3.2, it is presented that there was no significant difference between the results concerning the order of the paths. However, in the numbers shown in figure 4.16 one can see a pretty big difference in the standard deviation, with 64.2 for the first path and 31.39 for the second path. This indicates that when participants had their first attempt, the results were spread out over a broader range, indicating worse results. Perhaps this source of error could be eliminated if three different paths were created, and all the participants were to carry out three attempts, where only the last two would influence the experiment, and the first were only for learning. This would, however, also result in the experiment taking even longer, and there would be fewer participants being available and willing to participate.

From the correlation test we could see that there were a significant positive correlation between the SBSOD score and the wayfinding performance for the second attempt. As written in section 4.3.3, this actually indicates negative results. This go against previous research which have shown that better spatial

abilities yield better wayfinding performance [24]. One possible reason for this may be that persons with a high spatial ability might be used to navigating in the real world where there are more significant characteristics such as landmarks or rivers. As this experiment only have simple building models with no textures or any distinct features, this might cause confusion and result in worse performance. As none of the correlations except the SBSOD - Mean degrees for the last path is not significant, in addition to the significant results conflicting with previous research, the correlations have to be considered with caution.

The number of participants is also one aspect to take into consideration. Only 20 participants were conducting the experiment, in addition to the four persons taking part in the pilot test. This may be too few to be able to make any conclusion on whether shadows affect wayfinding or not. Since there were some technical issues while creating the experiment, there were some time limitations for conducting the experiment. As a result, there was not enough time to have as many participants in the experiment as the author originally would have wanted. The fact that the time was of the essence, it was also most convenient to use students as participants, since the experiment would take place at the university. This thesis could have benefited from having a greater sample size, with a broader span in age, education field and culture.

The limitation of time also made an impact on the pilot test. Preferably, the author would have liked to do an extensive pilot test to obtain even more feedback, which also could have been more detailed and reasoned. This would also require more time between the pilot test and the experiment in order to make alterations from the feedback. Perhaps this would have resulted in the final experiment being even better and perfected, ultimately giving better results in wayfinding performance. Another weakness of the pilot test was that there was no statistical analysis of the results obtained. Given the number of participants in the pilot trial, the results here would not be conclusive. However, they could give an indication of what could be expected from the experiment. In addition, the metrics used in the statistical methods would have been tested to see whether some alterations had to be made.

Motion sickness is mentioned several times in this thesis, and with good reason. While the author was creating the VE, she felt sick several times and needed to take longer breaks from the glasses, sometimes for hours. This caused a delay in the experiment, as the process could not be as fluent and efficient as desired. The cause of motion sickness led to participants feeling different levels of sick. Someone did not notice anything. However, many of the participants felt a strong discomfort. This prompted some participants to rush through the experiment as fast as possible without thinking much about the surroundings. On most of these occasions, when asked to point in the direction of the starting point, the participants said that they did not pay attention to the paths; they just wanted to be done as fast as possible. Some participants also needed to take a break during the experiment, which contributed to losing the sense of presence within the VE. This could also have caused worse results. In addition, some participants chose to close their eyes each time they took a turn to avoid feeling very sick, this also could have caused them to lose some focus, and there was some uncertainty when pointing back to the start.

When asked about their daily wayfinding, most participants stated that they sometimes use buildings and familiar areas as a guide when navigating familiar places. Still, they rely entirely on map applications such as Google maps or Apple maps when navigating new places. They only follow the guidance that says what direction to walk/drive and, for the most part, do not make themselves familiar with their surroundings. This indicated that the participants do not recognize shadows as an aid for finding their way. In a familiar place, other factors are easier to take into consideration. Unfortunately, when in an unfamiliar place, we are, in 2022, too comfortable with technology and only use a digital map to find our way. Because of this, people are maybe too reliant on helping aids, which might cause a lack of knowledge on how to use one's surroundings for wayfinding.

Chapter 6

Conclusion

This thesis investigated how shadows influence wayfinding performance and whether the influence of spatial abilities and presence is affected by shadows. Two VEs were developed, one with shadows and one without, and used to conduct an experiment using the VR device Oculus Quest. The experiment contained 20 participants who were instructed to complete a task twice, once for each VE. The participants were asked to walk a path and, at the destination, point to the direction of origin. In order to answer research question number 1, the angles between the correct direction line and the direction pointed were measured and analyzed using standard statistical methods.

The results showed no significant difference in the performance between the VE with shadows and the VE without shadows. However, the standard deviation did somewhat differ from their first attempt when looking at the path walked on the participants' second attempt. This argues that the participants learned how to use their surroundings to achieve better results after completing the task once.

Two questionnaires were also given to the participants to see if spatial abilities or level of presence could affect the wayfinding performance. The correlation between the results from the questionnaires and the experiment was calculated in order to answer research question 2. Because the majority of the correlation coefficients were insignificant, and the significant coefficient contradicted earlier research, these findings should be regarded cautiously.

This thesis did not find any significant connection between the use of shadows and the wayfinding performance. Still, it got clear that VR is a helpful aid when wanting to conduct experiments in controlled environments. Therefore, it is a field that should be explored further to see if other approaches or factors could yield better results.

Chapter 7

Further Work

After discussing the results of this thesis and finding no significant differences, the author thinks it would be interesting to examine this topic further. It would be interesting to carry out an experiment with a more substantial number of participants to see if this could affect the statistics. Also, it would be interesting to conduct an even more extensive experiment, digging deeper into the wayfinding habits of the participants.

One of the things that could be interesting to see is if the same kind of experiment would give other results if the buildings were entirely without shadows, not only without the casting of shadows from the buildings. Another method to test the effect of shadows could be to guide the participants through two different paths, one with shadow and one without, and then make them take off the VR glasses and draw the route on a map of the area.

Perhaps altering the experiment's methodology could have changed the results somehow. For example, with more time available, a more advanced city model could have been made, and a larger set of tasks could test the wayfinding performance even more profoundly than the method presented in this paper.

When discussing the results, it was mentioned that there was little diversity among the participants. Something that could be interesting to look into is conducting a similar experiment with two different generations and then compare the

performance between the two age groups with one another. The younger generation has grown up with all this technology and is therefore totally dependent on this when navigating. It would be interesting to see if the older generation thinks differently and would actually use the shadows more consciously than the younger ones.

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Appendix

A Spatial abilities questionnaire

Spatial Abilities

Please fill out the statements with an x on the answer that is most suitable for you.

1. I am very good at giving directions.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

2. I have poor memory for where I left things.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

3. I am very good at judging distances.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

4. My sense of direction is very good.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

6. I very easily get lost in a new city.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

7. I enjoy reading maps.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

8. I have trouble understanding directions.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

9. I am very good at reading maps.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

10. I don't remember routes very well while riding as a passenger in a car.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

11. I don't enjoy giving directions.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

12. It's not important to me to know where I am.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

13. I usually let someone else do the navigational planning for long trips.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

14. I can usually remember a new route after I have traveled it only once.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

15. I don't have a very good mental map of my environment.

1 (Strongly agree)	2	3	4	5	6	7 (Strongly disagree)

Source: Hegarty et al. [24]

B Presence questionnaire

Presence Questionnaire – How immersive was the virtual environment?

1. Please rate your sense of being in the VE, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place.

   I had a sense of being in the world:

1 (Not at all)	2	3	4	5	6	7 (Very much)

2. To what extent were there times during the experience when the VE was the reality for you?

   There were times during the experience where the VE was the reality for me:

1 (At no time)	2	3	4	5	6	7 (Almost all the time)

3. When you think back about your experience, do you think of the VE more as images that you saw, or more as somewhere that you visited?

   The VE seems to me to be more like:

1 (Images that I saw)	2	3	4	5	6	7 (Something that I visited)

4. During the time of the experience, which was strongest on the whole, your sense of being in the VE, or of being elsewhere?

   I had a stronger sense of:

1 (Being elsewhere)	2	3	4	5	6	7 (Being in the VE)

5. During the time of the experience, did you often think to yourself that you were actually in the office space?
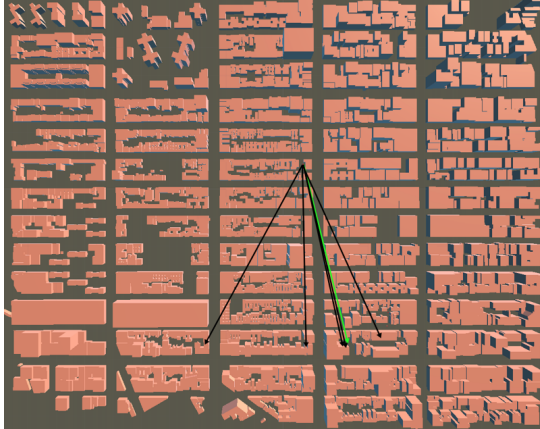
   During the experience I often thought that I was really standing in the VE:

1 (Not very often)	2	3	4	5	6	7 (Very much so)

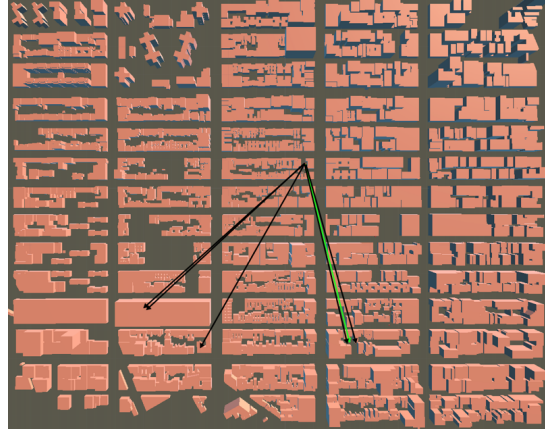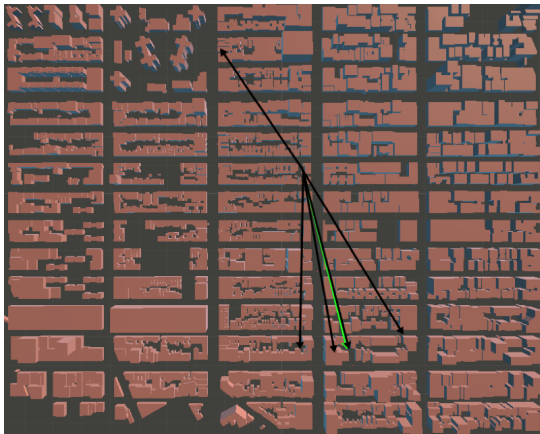Source: Slater et al. [54]

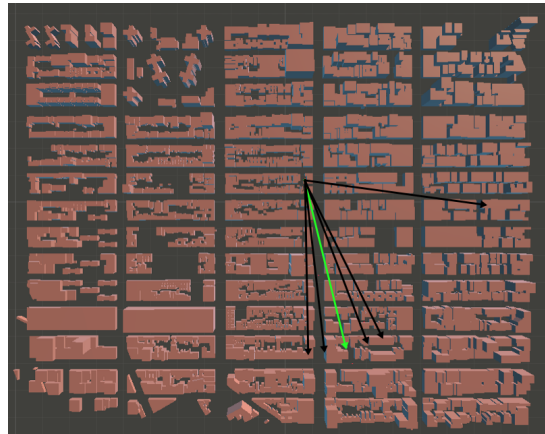# C   Results

(a) First route

(b) Last route

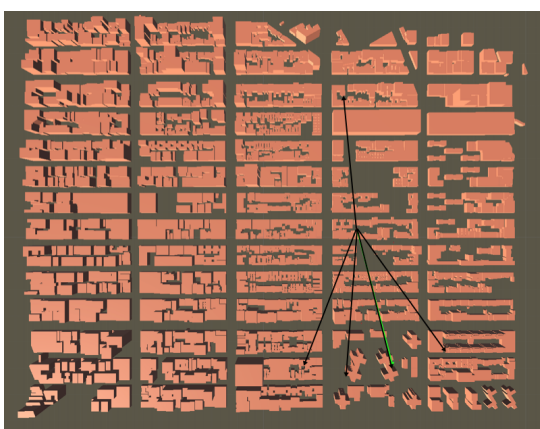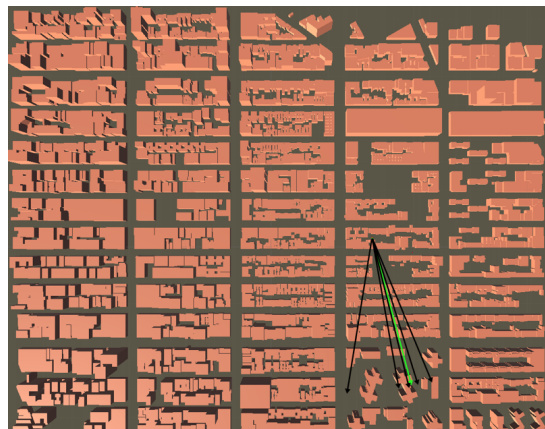Figure C.1: Results of path 1a

(a) First route

(b) Last route
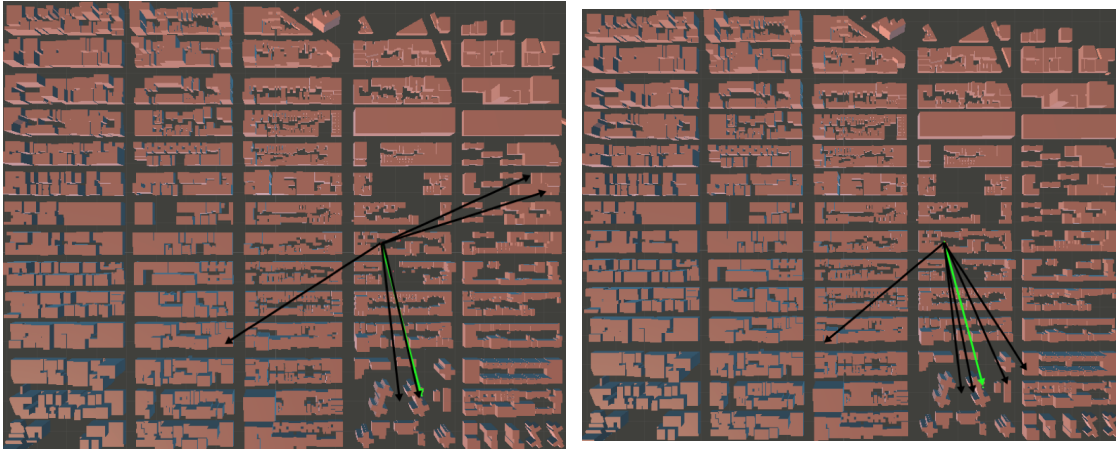
Figure C.2: Results of path 1b

(a) First route

(b) Last route

Figure C.3: Results of path 2a

(a) First route

(b) Last route

Figure C.4: Results of path 2b

	Female		Male	
	Path 1	Path 2	Path 1	Path 2
Number of observations	10	10	10	10
Mean x (s)	162.737	126.094	160.19	130.655
Median (s)	163.555	116.01	158.54	117.06
Minimum (s)	109.18	101.97	109.18	98.27
Maximum (s)	222.28	159	222.28	234.5
Standard deviation of x (s)	33.06	23.249	33.059	39.48

Table C.1: Results time

	Females	Males
Number of observations	10	10
Mean x (degrees)	4.4	2
Minimum (degrees)	-100	-171
Maximum (degrees)	161	65
Standard deviation of x (degrees)	58.2	44.46

Table C.2: Results for females vs males