Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

Jørgen Mortensen

Wayfinding in Virtual Environments

Exploration of how different level of detail affect human wayfinding

Master's thesis in Engineering and ICT
Supervisor: Terje Midtbø
June 2020

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Master thesis

(TBA4925 - Geomatics, Master thesis)

Spring 2020
for
Jørgen Mortensen

Wayfinding in Virtual Environments

- Exploration of how different level of detail affect human wayfinding

BACKGROUND
In 2019, Oculus Rift released new and better versions of their VR-equipment, called Oculus Quest. This equipment includes input-equipment that can register hand movement. Mainly, the equipment was made for gaming, but the thought about this master thesis is to study how the equipment can be used in interaction with 3D models in the virtual world, by testing if different level of detail of buildings affect human wayfinding.

TASK DESCRIPTION
The student is supposed to make a city model in Unity, which will be presented by buildings with different level of detail. The models will be used in an experiment where the participants are navigating through the city model, in order to explore how a difference in level of detail affect human wayfinding.

Specific tasks:

- Study relevant literature for the chosen subject.
- Study use of virtual reality and its application.
- Construct a city model with varying level of detail.
- Design an experiment where the participants navigate through the city model with either a low or high level of detail.
- Analyse and compare the results obtained in the experiment to earlier related experiments.

ADMINISTRATIVE/GUIDANCE

The work on the Master Thesis starts on January 15th, 2020

The thesis report as described above shall be submitted digitally in INSPERA at the latest at June 11th, 2020

Supervisors at NTNU and professor in charge:
Terje Midtbø

Trondheim, February, 2020

NTNU
Faculty of Engineering
Department of Civil and Environmental Engineering

Date	Our Reference
14.5.2020	
Your date	Your ref

Extraordinary circumstances due to the Corona pandemic

This Master thesis is based on work that was accomplished in the spring semester 2020. In this period the Corona pandemic was active and influenced the work of several master students. The grading of the thesis must take the pandemic situation into consideration.

If this Master thesis is affected by the Corona pandemic, the student will point out the influenced elements in the beginning of the report. More details about this may also be explained later in the thesis.

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Abstract

Wayfinding tasks are an important part of people's everyday lives. When going to school or work, or traveling to a new place, wayfinding is needed. Despite that people are used to this concept in the real world, wayfinding in virtual environments are unfamiliar to most. This thesis evaluates wayfinding performance of low level of detail models and high level of detail models in virtual reality.

The virtual reality system Oculus Quest was used in a trial with four participants. The participants performed four wayfinding tasks in two city models, where the level of detail differed. The metrics measured included the total time used, the number of errors made and the number of times instructions were used. Two questionnaires were filled out in order to map spatial abilities and presence.

An introduction to virtual reality, Oculus Quest and wayfinding in virtual environments is given. The correlation between the questionnaire data and the results from the trial is discussed as well as the difference between the results in the different city models.

As the results were greatly affected by the COVID-19 situation, they cannot be seen as conclusive. The results showed no indication that wayfinding performance in terms of completion time was increased by the use of high level of detail, but they indicated that the amount of errors and number of times instructions were used went down as the level of detail got higher.

For further work, a larger sample size is needed in order to get enough observations to make a conclusion about whether or not the level of detail affect wayfinding performance.

Sammendrag

Navigasjonsoppgaver er en viktig del av folks hverdag. Når man skal til skole og jobb, eller reiser til nye steder er navigasjon nødvendig. Til tross for at folk er vant til dette konseptet i den virkelige verden, er navigasjon i virtuelle miljøer ukjent for de fleste. Denne oppgaven studerer hvordan lav og høy detaljeringsgrad i 3D-modeller påvirker navigasjon i virtuelle miljøer.

Virtuell virkelighet-systemet Oculus Quest ble brukt i et forsøk med fire deltakere. Deltakerne utførte fire navigasjonsoppgave i to bymodeller, en med høy detaljeringsgrad og en med lav detaljeringsgrad. Totaltiden som ble brukt, antall ganger det ble begått feil og antall ganger instruksjonene ble brukt ble målt. To spørreskjema ble besvart for å kartlegge romlige egenskaper og tilstedeværelse.

En introduksjon til virtuell virkelighet, Oculus Quest og navigasjon i virtuelle miljøet er gitt. Korrelasjonen mellom data fra spørreskjemaene og resultatene fra forsøket er diskutert, i tillegg til forskjellen mellom resultatene fra modellen med lav detaljeringsgrad og modellen med høy detaljeringsgrad.

På grunn av at resultatene var sterkt påvirket av COVID-19-situasjonen, kan de ikke bli sett på som konkluderende. Resultatene viste ingen indikasjoner til at navigasjonen ble forbedret når man ser på den totale tiden brukt, men de indikerte at antall feil begått og antall ganger instruksjoner ble brukt gikk ned når det var høyere detaljeringsgrad.

For framtidig arbeid, flere deltakere må bli inkludert i forsøket for å få nok observasjoner til å kunne konkludere om detaljeringsgraden på bygningene påvirker navigasjonen i virtuelle miljøer.

Preface

This thesis is part of the master thesis assignment in the course TBA4925 at the specialization of Geomatics at the Norwegian University of Science and Technology (NTNU). The work with this thesis was done during the spring of 2020, starting in January and ending in June.

I would like to thank my supervisor Terje Midtbø for helping and guiding throughout the period of writing, as well as providing the technical equipment necessary to complete the trial. He provided helpful insight, particular when the COVID-19 situation forced me to change the scope of the thesis.

I would like thank my roommates for taking part in the trial and a special thanks my friend Jakob Sterri, for lending me his computer when mine suddenly did not work. I would also like to thank my parents and my girlfriend Zanna Gleditsch for all love and support throughout the period of writing and for proofreading the thesis for me. Without their help, the results of this thesis would not have been the same.

Trondheim, June 8, 2020

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Abbreviations and Acronyms

AR	=	Augmented Reality
BOOM	=	Binocular Omni-Orientation Monitor
CAVE	=	Computer Assisted Virtual Environment
DoF	=	Degrees of freedom
FSD	=	Floor-Supported Display
H-A	=	Task A in high LOD model
H-B	=	Task B in high LOD model
H-C	=	Task C in high LOD model
H-D	=	Task D in high LOD model
HMD	=	Head-Mounted Display
HSD	=	Hand-Supported Display
L-A	=	Task A in low LOD model
L-B	=	Task B in low LOD model
L-C	=	Task C in low LOD model
L-D	=	Task D in low LOD model
LOD	=	Level of Detail
SBSOD	=	Santa Barbara Sense of Direction Scale
VCASS	=	Visually Copled Airborne Systems Simulator
VE	=	Virtual Environment
VR	=	Virtual Reality

Chapter 1

Introduction

Wayfinding is the spatial knowledge about one's current location, destination and the spatial relation between them (Cubukcu, 2003). By using information about where people are located, which direction they are facing and in which direction the destination of their wayfinding task is, they are able to find their way from the origin to the destination by using the principle of wayfinding. By using elements in the real world, often assisted by a map, people are able to take navigational decisions to find their way through complex environments. As most people do not have the capability to know a city just by looking at a map beforehand, good navigational skills are vital in order to avoid getting lost in new environments and to get to where they need to go the most efficient way. This gets more and more important due to increasing globalisation and the fact that people have a tendency of traveling to new and unfamiliar places.

While wayfinding in the real world is something people do on an everyday basis, wayfinding in virtual environments (VEs) is much more uncommon. By using virtual reality (VR), people have the ability of exploring a world different than their own, or explore VEs of real world cities, without actually being there physically. As the real world cannot be represented completely authentic in the VE, as this would require 3D models to consist of an unlimited number of triangles and polygons, how will this reduction of level of detail (LOD) affect wayfinding performance? This thesis aims to explore the answer to that question. With better insight in this topic, VR programmers could have a better understanding of how they should develop the 3D models of their applications when making city models where navigation is needed. As higher LOD may affect application performance, optimizing the trade-off between the LOD needed and the application's rendering speed could be of great value.

In this thesis, the VR system Oculus Quest is used to perform wayfinding tasks in a VE. By having two different city models, one with low LOD and one with high LOD, there is planned an experiment in order to answer the following research questions:

1. Does the LOD of the buildings in the 3D model affect the time it takes to navigate a given wayfinding task?
2. Do spatial abilities and the level of presence affect performance in wayfinding tasks differently in low LOD models and in high LOD models?

Spatial abilities may have an effect on the individuals' wayfinding performance, and are therefore collected and compared to the wayfinding performance for each participant, by using the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty et al., 2002).

The main goal of VR is to give the user a sense of actually being in the VE. By feeling like one belongs in the environment, one might perform more like one would in the real world. The level of presence experienced by the participants are registered and compared to the results of the wayfinding performance to see what effect presence has.

Initially, previous research in the field of wayfinding in VEs will be explored to gain insight in what has been previously done, followed by an explanation of theory regarding VR, the Oculus Quest, wayfinding and LOD in order to understand the academic background of the thesis. Further, the methodology behind the development of VEs and the planning of the experiment will be shown. Finally, the results obtained from the experiment will be discussed before concluding with respect to the research questions.

Chapter 2

Literature Review

As the Oculus Quest was released in 2019, research regarding wayfinding in combination with Oculus Quest is limited. However, there has been carried out a lot of research in the field of wayfinding combined with other VR systems. Due to the flexibility of VR systems, for example the fact that the developers can control the environment, they prove to be a great aid in research, particularly in the field of wayfinding when having to virtualize real world environments. By using VR, one can easily target very specific research questions and shape experiments towards them, which may result in more conclusive results.

In the article by Bowman and McMahan (2007) they concluded, based on empirical studies, that full immersion is not always necessary. This implies that one can transform scenarios and environments from the real world into the virtual world and still perform scientific experiments. This supports the use of VR to answer specific research questions in various fields. The article also explores how VR has been used in various fields like phobia therapi, military training and entertainment.

Tang et al. (2008) explored the difference of having emergency signs in buildings when performing indoors wayfinding. By using VR, they constructed three different scenarios where the emergency signs differed between no emergency signs, old-version emergency signs and new-version emergency signs. They were able to quickly and easily change and control the environment in order to create the three different scenarios efficiently due to the efficient development of VEs. The goal of the paper was to study if emergency signs are an advantage when it comes to indoors wayfinding. It was clear that wayfinding with signs was a clear advantage, as it took longer time to navigate out of the buildings when no signs appeared. Therefore the paper proved that people performed better when having navigational aid when performing a wayfinding tasks, in this case with signs inside of a building.

Similar to the article written by Tang et al. (2008), Vilar et al. (2014) focused on exploring how to aid wayfinding in indoor environments. They conducted their experiments by providing vertical and horizontal signage as aid and measured the performance of the participants. In order to have something to reference the performance metrics to, they used no signage as a baseline. Different metrics were taken into account, such as successfully navigating from the origin to the destination, the distance traveled, the time spent and the number of pauses.

The software engineer Martin Reddy has done a lot of research in the field of LOD and computer graphics, mainly during the work of his doctoral thesis. In order to achieve the goal of reducing the lagging, or latency, in VR systems, Reddy (1997) proposed that "optimising the visual complexity of any arbitrary computer-generated virtual environment (VE)" would achieve this goal. By exploring the field of human visual perception, Reddy found out that not all objects in a VE needed to be perfectly detailed for humans to understand the context of the object. By decreasing the LOD of the objects that did not need to be of a high detail level, the system that provided the VE obtained a reduction in latency, which again affected the application's usability in a positive manner.

Related to the paragraph above, Reddy (1995) explored which different VR systems provided LOD changing techniques. The different techniques mentioned were manual LOD, distance LOD, load balancing and LOD generation. It was conducted a survey where 15 different VR systems were tested and categorised with Yes, No or Limited, based on if they supported the four different techniques mentioned. The results showed that the majority of the systems supported manual LOD, where the programmer specifies the LODs for the application, and distance LOD, where the LODs are decided automatically by the distance from the camera to the objects in the scene. The other two techniques, load balancing, where the system is tested by trying to change the LODs in order to keep a fixed frame rate, and LOD generation, that creates different LODs from a polygon model, where not that commonly used. From the research of Reddy, it got clear that there was a focus on LOD, and that it had to be taken into account. Even though the article was written in 1995, and especially the computer's hardware has changed a lot, LOD needs to be taken into account as it is an important issue today also.

As for exploring the field of LOD in relation to graphics systems, Reddy conducted research when it comes to trying to find the ultimate LOD regarding performance optimization, through the article ”Specification and evaluation of level of detail selection criteria” (Reddy, 1998). Because the LOD has an important role in graphic systems, that is by varying the amount of information shown at each moment, setting the LOD such that it can provide enough information, but not too much, is important. Reddy mentioned a critical downside of changing the LOD, because it can cause an abrupt change in the scene. From a user point of view this would be a clear disadvantage. In order to find an optimal selection of LOD, Reddy used parameters such as size, distance and velocity to dynamically decide what LOD the scene could contain. By doing this, it was shown that the speedup of the system was up to 4.5 times as fast after doing the optimisations, resulting in a much better performance.

Although Oculus Quest is fairly new, other Oculus systems such as the Oculus Rift has been used for conducting various research. In the field of wayfinding, topics lik the study of map orientation (Henriksen and Midtbø, 2015), lighting systems for rail tunnel evacuation (Cosma et al., 2016) and the influence of landmarks on wayfinding (Sharma et al., 2017) have been explored by using the Oculus Rift. This shows the flexibility and adaptability of VR systems and shows that it is a good aid when wanting to facilitate controlled environments and experiments that are not so easy to do in the real world.

Chapter 3

Basic Theory

For the purpose of understanding the concepts behind the research questions explored and experiment conducted in this thesis, a lot of basic theory has to be researched beforehand. Various fields such as VR, wayfinding and LOD are all important to explore in this thesis' case, along with a basic understanding of what the Oculus Quest is and how it works. This chapter aims to explain the theory behind these fields and give examples of applications used in the respective fields mentioned.

3.1 Virtual Reality

In the book "Silicon Mirage; The Art and Science of VR" (Aukstakalnis and Blatner, 1992), VR is defined as "a way for humans to visualize, manipulate and interact with computers and extremely complex data". This definition indicates that by using VR, one gets a lot of possibilities in various fields that applies and requires visualization of data. For a more abstract definition, Biocca and Levy (1995) wrote: "VR is not a technology, it is a destination." What can be interpreted by this quote is that by developing VR systems, one can transfer the user of the system into a world different than his own. The behaviour and cognition of the user do not have any limits in the VE and the VR system stimulates the user's senses so the user gets an immersive experience.
In this section, the field of VR will be explored by looking at it with a historical view and an up-to-date view of what VR is and what it can be used for.

3.1.1 History

From a human being perspective, exploration through sight and vision is a fundamental thing, for example by traveling places or listening to music. This explorative desire of human kind is what has triggered the development of technology, including VR. Ever since the resurgence of modern photography in the early 19th century (Wikipedia Contributors, 2020), people have been able to use visual effects to experience and imagine a reality different than their own. By looking at a captured image of an unfamiliar place, one is able to get a feeling of how the world looks like outside one's own home area.

Following the advances in technology during the 20th century, the development of products such as television broadcasts, movies and video games made it easier for people to imagine things they had not done before, by using this imagination to take themselves into interesting worlds. The more visual stimulation available, the more could the imagination increase, which is what the concept of VR is based upon. By using the human sense perception, mainly eyes and ears in this case, VR systems put the users in a world different than their own, where they can perceive, move and interact with the VE.

Looking at VR in its beginning, one can transfer the concept to flight simulators. As pilots needed to be able to train and experience flying the easiest and cheapest way possible, flight simulators were created in order to make it possible for the pilots to simulate being in an airplane. The first flight simulator, the Link Trainer Blue Box (Virtual Reality Society, 2020), was made as early as around 1930. It was used both commercially and military, providing a safe way for pilots to enhance their flight skills.

Figure 3.1: Link Trainer Flight Simulator - The first commercial flight simulator (Interesting Engineering, 2019)

After the mid 20th century, the VR technology increased by a large amount. The development of microprocessor technology made it possible to make faster computers, with better and faster graphic boards than before. This made a great deal for VR systems, providing some of the following systems, all developed after the mid 20th century (Mazuryk and Gervautz, 1999):

- **Sensorama** - A VR system from 1962 that contains features to simulate environments close to real life, such as color and stereo film, sound, scent, wind and vibration experiences.
- **Visually Coupled Airborne Systems Simulator (VCASS)** - A head-mounted display (HMD) system serving the role as an advanced flight simulator from 1982. The HMD assists the pilots by telling the most optimal route to fly.
- **Binocular Omni-Orientation Monitor (BOOM)** - A VR system from 1989, which consists of a box with two eye holes, making it possible for the user to move through a virtual world.
- **Augmented Reality (AR)** - Technology that developed during the 1990s, which adds additional layers on top of the real world layer. AR can be thought of as a middle ground between VR and the real world, providing the possibility of seeing additional objects for users in reality.

The systems mentioned above show how fast VR has developed, resulting in a growing popularity. Nowadays, VR is not just a tool used by professional researchers or military, everyone can simply buy a VR system in almost every technology store. Factors like lower prices and the entry in the field of entertainment have contributed to the growing popularity. This can be shown by the acquisition of the VR company Oculus by Facebook in 2014 for $2billion (Facebook, 2014).

3.1.2 Degrees of Freedom

A very important concept when talking about VR is Degrees of Freedom (DoF). DoF is defined as ”the number of basic ways a rigid object can move through 3D space” (Google VR Developers, 2018). This means that there is a total of six DoFs. Three of the DoFs correspond to movement by rotation around x, y and z-axis, often called the pitch, yaw and roll, respectively. The other three DoFs correspond to movement along the axes, called translation.

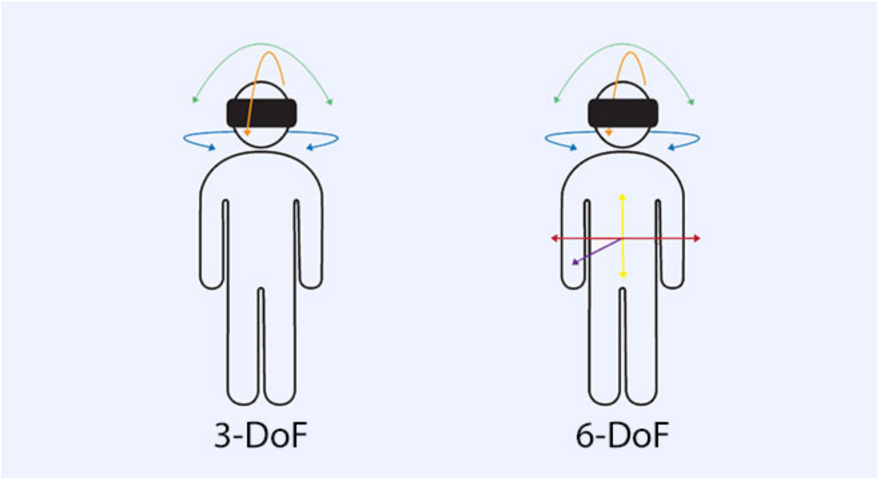


Figure 3.2: The different types of DoFs in VR (VirtualSpeech, 2019)

As seen from figure 3.2, one mainly differs between 3-DoF and 6-DoF in VR systems. 3-DoF uses only rotational movement, while 6-DoF uses both rotational and translation movement. This makes it possible for 6-DoF VR systems to move more freely in the VE, as the case is for Oculus Quest, which is written about in section 3.2.

3.1.3 Human Factors

One aspect that has to be taken into account when talking about VR, is the fact that it stimulates the human senses, giving the user a high level of immersion. This makes it important when developing VR systems to study human factors, in order to find out which of the human senses that need to be focused and stimulated the most.
The following distribution shows how the five different human senses contribute to attention (Heilig, 1992):

- Sight 70%
- Hearing 20%
- Smell 5%
- Touch 4%
- Taste 1%

The list shows that 90% of the attention contribution comes from sight and hearing, making it possible to increase the level of immersion by stimulating these two senses. By developing VR systems that use for example HMDs, which is explained in section 3.1.5, VR developers are able to create a more immersive experience for the users by capturing them with stimulation of the sight and hearing senses. More theory about how human factors have an affect related to wayfinding is described in section 3.3.2.

Motion sickness

Another important aspect to consider is motion sickness, also called simulator sickness. Motion sickness can be defined as ”a syndrome that occasionally occurs when physically stationary individuals view compelling visual representations of self-motion” (Hettinger and Riccio, 1992). This means that users of VR systems are exposed, especially in HMDs like the Oculus Quest. Because the user does not physically move, but uses joysticks for moving in the VE, there is a possibility that he might experience motion sickness. In an experiment setting, this may lead to aborts of the observations, which again may lead to worse results. Symptoms that may occur includes general discomfort, drowsiness, pallor, sweating, nausea and occasionally vomiting (Kolasinski, 1995).

When conducting an experiment in a VE, it is important to consider the eventual occurrence of motion sickness. Therefore, the participants of the experiment later in the thesis was encouraged to give an indication if they started to feel sick.

3.1.4 Applications

One of the most positive aspect of VR technology is its adaptability. Meaning, it can be used for a lot of functions and in several fields. The technology has broad possibilities of interfaces, which can be modified for specific tasks and research. By using coding and modeling, there are no limits to what types of VEs that can be made, giving researchers endless of opportunities when it comes to visualization and interaction with data. For experiments that need a high level of control, VR is optimal for such a purpose, as the wanted world can be created and unnecessary elements and objects can be left out.

A field where the use of VR has a lot of advantages is in the field of spatial data. Research in this field often require doing experiments in controlled environments, when for example performing outdoor wayfinding tasks. Bad weather conditions, excessive noise in the streets and interrupting pedestrians are all factors that may damage or contribute to bad results, which increase the need of control.

By making a VE, one can modify the environment in such a way that it leaves out the irrelevant elements and instead aims to explore a specific task. An example of research where environment control was needed is the article ”The interaction of landmarks and map alignment in you-are-here maps” (McKenzie and Klippel, 2014). As the goal of the paper was to explore how different settings of landmarks and map alignment affect the wayfinding performance, the need for creating numerous VEs was important. By using VR, different environments with different parameters can be made faster, which makes the research much more efficient.

Related to the spatial data field, data visualization has great advantages in VR. One particular field when data visualization is vital is in means of city planning. In order to create an optimal plan of how a city's architecture will look like after the construction process, VR can serve as the visualization tool. By modelling how the city will look like before starting the construction, politicians and architects will have a better tool for deciding what type of architecture should be built. How VR is applied in city planning processes have been shown to be of great value (Sunesson et al., 2008; Nguyen et al., 2016). By having the finished results visualized, the decision process will be greatly simplified, as well as making changes can be done faster.

VR does not just apply for usage in experiments for researchers and scientists, but also for enhancing skills at a professional level. Using VR as a tool in education, medicine and military may both enhance the skill practice, as well as reducing negative effects such as safety risks. Vera et al. (2005) explored how to use VR in education for people with learning difficulties by making a VE where learning by playing was in focus. For medicine purposes, VR can be of great advantage. By creating a learning environment which minimizes risks related to surgeries (Satava and Sherk, 2006), in particular , can provide necessary operational training for many surgical students, including eye operations (Sagar et al., 1994) and leg surgeries (Pieper et al., 1991). VR can serve as an important training tool in the military fields. Simulators can be of great importance for both reducing risks (Herrero and De Antonio, 2005) and also for mental therapy of soldiers (Reger et al., 2011).

VR is not only limited to applications in the professional market, but also in the commercial market. Particular in sectors where visualization and entertainment are required, such as for tourism, VR can be applied. By recreating sites that are dangerous for the public, VR makes it possible to explore these sites safely (Guttentag, 2010). Tourist locations can also take advantage of the entertaining factor of VR, like for instance museums (Wojciechowski et al., 2004), heritage sites (Gaitatzes et al., 2001) and theme parks (Wei et al., 2019).

3.1.5 Virtual Reality Graphic Displays

The most vital part of a VR system is the VR graphic display, a computer interface that has the functionality of presenting a synthetic world to the users interacting with the virtual world (Burdea and Coiffet, 2003). This is vital for the VR system so that the user can get an immersive experience. Today, there are a numerous different output devices that can serve the role as graphic displays in VR, all with different benefits and drawbacks. They are mainly split up into two different categories (Burdea and Coiffet, 2003):

- **Personal displays** - Graphic displays aimed for a single user
- **Large volume displays** - Graphic displays aimed for multiple users, gathered at the same location

Personal displays

As for personal graphic displays go, there are mainly three types to be considered: Head-Mounted Displays (HMDs), Hand-Supported Displays (HSDs) and Floor-Supported displays (FSDs). A clear benefit of personal displays is that the tool itself can be of a lower scale. As it should just serve as a display for one user at a time, one does not need a whole room, which can save cost and space. An obvious drawback is the lack of sharing. As the name suggests, it is not possible for other users to take part in the VR experience when using personal displays, which may have a negative effect on interest.

The most common and most known personal graphic display in VR is the HMD. As seen in figure 3.3, a HMD is a device that is worn on the user's head like a pair of binoculars. The HMD contains sensors which can register rotational movement of the user's head, making it possible to look around in the environment. An advantage of HMDs is that the user is able to interact with the virtual world by using joysticks, as his hands are free due to the head mounting of the display system. VR systems like Oculus Rift and Oculus Quest, which is used in this thesis, use a HMD (Oculus, 2019a).

Figure 3.3: An example of a HMD, Oculus Quest (Oculus VR, 2018)

HSDs have a lot of similarities with the HMDs. Similarly to the HMDs, the HSDs consist of a pair of binoculars that one can use to look into. The difference is that the user has to hold it with his hands, preventing the possibility of interacting with the VE by the use of joystics. However, the binoculars usually contain buttons which make it possible for the user to interact with the environment by pressing the different buttons available. In figure 3.4, an example of a HSD is shown.

Figure 3.4: An example of a HSD, Virtual Binocular SX (Engineering Systems Technologies, 2020)

FSDs can be considered as an earlier version of the HMDs. Instead of consisting of a helmet with binoculars, they have a mechanical arm that serves as the tool for sensor registration. By this, the movement of the head can be tracked without any delays, as it is a mechanical arm, making the rendering of images faster. A downside of floor-supported displays is that the user has a limited area where it is possible to move, as he has to be located inside the length of the mechanical arm.

An example of a floor-supported display is BOOM, as was mentioned in the VR history section (Onyesolu and Eze, 2011).

Figure 3.5: An example of a FSD, BOOM (Onyesolu and Eze, 2011)

Large Volume Displays

As for large volume displays go, these can be categorized into two categories: Monitor-Based Large-Volume Displays and Projector-Based Displays. An advantage with these types of displays is that if a group of researchers want to cooperate in an experiment or study, large volume displays allow them to do so. These types of displays make sharing and collaboration simpler and more effective.

For the monitor-based large volume displays, the user has to wear shutter glasses that are coupled with a monitor. The user looks at the monitor through the shutter glasses, and are able to obtain right and left eye images. These obtaining of images to both eyes gives the user a 3D looking feeling, and the user is then able to see the images as a 3D scene.

The projector-based displays, as the name suggests, take advantage of a projector in order to make the room the users are in like a VE. By using this type of display, the possibility of cooperating while in the same VE is present. The downside about this type of display is that the cost is high and one need to fit the equipment to a whole room. An example of this type of display is the CAVE Automatic VE, as can be seen in figure 3.6 (Cruz-Neira et al., 1992).

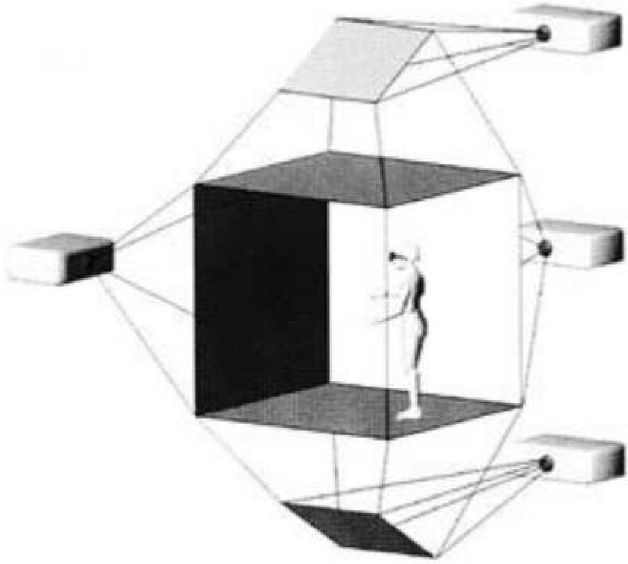


Figure 3.6: An example of a projector-based display, CAVE (Cruz-Neira et al., 1992)

3.2 Oculus Quest

As the popularity of VR grew, more and more products were developed and made available to the public. However, VR equipment was not usual for the common man, due to still high costs and other popular gaming engines. During the 2010s this changed. A VR company called Oculus initiated in 2012 a crowd-sourced founding project through the crowd sourcing platform Kickstarter (Kickstarter, 2012). The goal of the company was to raise enough money for its new VR system Oculus Rift, a new HMD that aimed at providing VR technology to a more reasonable price and ease the development process of applications, making it available to a whole new market of users.

The aftermath of the success of Oculus Rift (Partleton, 2019) made it possible for Oculus to continue their development in the VR market, proved by the acquisition by Facebook in 2014 (Facebook, 2014). After the acquisition, Facebook CEO Mark Zuckerberg has stated: ”Our mission is to give anyone the power to express anything they’re thinking about or want to experience” (Dave Smith, 2016). What Zuckerberg meant by this is that he wants to make sure to give the possibility of living and experiencing whatever the people want in an immersive way through the use of VR. Oculus continued to improve their development of VR systems, culminating in the release of Oculus Quest in the spring of 2019, their first ever all-in-one gaming system for VR (Oculus, 2019b). By creating a standalone system, the user was able to play without having to worry about wires or having a computer. All that was needed to experience VR was the HMD and two handheld controllers.

3.2.1 Components

Oculus Quest is a HMD VR system, which serves as a standalone system. This means that all of the processing is done locally inside the Quest and it does not need any computers or exterior wires to function properly. The system consists of the following six components:

- **Head-mounted display** - The HMD serves as the screen, giving the user a field of view of 110 degrees and 6 degrees of freedom for rotation and translation movement (Hillmann, 2019).
- **Touch controllers** - Two handheld controllers are provided, each of which containing a joystick and four buttons. These make it possible to interact and move in the VE.
- **AA batteries** - For powering the touch controllers.

- **Connection wire and power adapter** - A connection wire for developing purposes, i.e. transferring applications from the computer to the Quest.
- **Spacer** - For packing purposes.

In figure 3.7, the different components of the Oculus Quest system is shown.

Figure 3.7: The different components of the Oculus Quest system (Oculus, 2019b)

3.2.2 Technical Specifications

A number of technical specifications of the Oculus Quest is listed below (Hillmann, 2019; Rogers, 2019; Oculus Developers, 2019):

- Display panel: OLED
- Display resolution: 1440 x 1600 pixels per eye
- Refresh rate: 72 Hz
- CPU: Qualcomm Snapdragon 835
- GPU: Qualcomm Adreno 540
- 4GB RAM
- Audio: Fully integrated open ear

- Battery: Lithium-ion, up to 2-3 hours of playing time depending on what is being played
- 6-DoF
- Weight: 571g
- Lens Distance: Adjustable

3.2.3 Benefits

Even though Oculus reached high popularity due to their work with Oculus Rift, there was a reason why the Quest was developed. By making a standalone headset, where all of the computations happen inside the HMD, various benefits occur. The most advantageous benefits are those related to immersion. When the user is able to avoid thinking about moving outside of the perimeters of the connected wires, as the case was for the Rift, a much more immersive experience will be obtained. As the Quest consists of a HMD and two touch controllers, the user feels free to move wherever he wants and really immerse himself into the VE. A helpful function of the Quest is that the user can draw a boundary area, where he is certain to move without bumping into any obstacles. When approaching the boundary, the Quest gives an alert and the user can turn and relocate in order to be safe. The fully integrated open air audio also provides a higher level of immersion, by not needing to use headphones while wearing the Quest. As mentioned in section 3.1.3, hearing contributes to 20% of human attention, meaning that sound is vital for a fully immersive experience.

3.2.4 Drawbacks

One of the Quest's biggest benefits is also one of its drawbacks, the fact that it is standalone. As all of the computations happen inside the Quest, it will not be able to compete with the processing power of computers. By having a computer to process together with the VR system, computations would execute faster, providing a faster system. This may lead to a worse frame rate and in worst case lagging, which can cause loss of information for the user of the system, which again may lead to loss of interest in the system. Another drawback of the Quest, as with many other VR systems, is the lack of screen sharing. If two people are in the same room and want to follow the screen of the other, this is not possible without a third party screen recorder. Therefore, having for example a group of friends playing together on the Oculus Quest would be rather difficult.

3.3 Wayfinding in Virtual Environments

Wayfinding has been defined as the ”cognitive and corporeal process and experience of locating, following or discovering a route through and to a given space” (Symonds et al., 2017). By using navigational aid, such as buildings, street patterns and landmarks, one has the tools to navigate from the origin to the destination in the most efficient way. As there are individual differences regarding how skilled people are in wayfinding, a number of factors, both human and environmental, have an impact on wayfinding performance. In the upcoming section, such factors, and how these factors affect wayfinding particular in VEs, will be explained.

3.3.1 Navigational Aiding

When performing a wayfinding task, it is important to have the proper navigational aiding to help reach the destination of the task. It is important to know when to turn, which way to turn and how long one has to go before a turn has to be made. The aid that most people think about when talking about navigation and wayfinding is the map, either paper or electronic. However, there are many more tools to support navigational aiding, particular in VEs, and all these tools can be classified into five categories (Chen and Stanney, 1999):

1. Tools that display an individual’s position
2. Tools that display an individual’s current orientation
3. Tools that log an individual’s movements
4. Tools that demonstrate the surrounding environment
5. Guided navigational systems

Category 1 and 2 are used for spatial-orientation tasks. For example by using a GPS and a compass, one can orientate oneself without the use of distinct features such as landmarks or other reference points. These tools are important as maintaining the orientation is vital in order to perform wayfinding tasks (Gärling et al., 1983). Category 3 tools are more uncommon, especially in the real-world. However, in a VE one can think about a category 3 tool as very useful, for instance if one is navigating through a virtual city and takes a wrong turn. By logging the movements made, one can be able to backtrack the path and come back to the original turning point, which can be important in order to not getting lost. Typical category 4 tools are maps or radars, which allows one to see what the surroundings look like. By having a category 4 tool available, it is possible to plan more steps ahead, as one can see more than just the buildings in front. Category 5 tools can be thought of as tools that do the wayfinding for you. By following the directions that for example a modern GPS gives, one can get from A to B without any decision making.

For developers of VEs, it is easy to think about maps as the most intuitive navigational aid for wayfinding tasks. As it is both simple to develop a map and visualize it on a screen, it is an efficient tool for navigation. However, maps are not always the most efficient aiding device. There has been shown that other navigational aids such as audio listening for drivers and that signs perform better in wayfinding and that the participants reach their destination faster by using them (Streeter et al., 1985; Butler et al., 1993). As the objectives of wayfinding tasks can be very different from each other, VE developers need to take this into account. For instance, a wayfinding task where the only objective is to get from A to B as fast as possible would take advantage of a category 5 tool. On the contrary, if the task aimed at providing the user with spatial knowledge along the path, a category 5 tool would work against its purpose, as using guided navigational systems have a tendency of decreasing spatial knowledge acquisition (Parush et al., 2007). Hence, a correct choice of navigational aiding is important when developing a VE.

3.3.2 Factors Influencing Wayfinding

When conducting a wayfinding experiment it is important to understand some of the factors that may have an influence on the wayfinding performance. As there might be a lot of reasons to whether or not wayfinding performance is different between individuals, both individual factors and environmental factors must be taken into account in order to carry out a thorough analysis of the results obtained.

A human factor that shows individual differences and has been well documented is how good a person's spatial abilities are (McGee, 1979). Spatial abilities have been defined as "how people mentally represent and manipulate spatial information to perform coginitive tasks" (Hegarty and Waller, 2005), which means that the better spatial abilities a person has, the better he is to understand and use the spatial information given. A lot of different methods have been proposed to map a person's spatial abilities, and in this thesis the SBSOD has been used. This can be read about in section 4.2.3.

Another important human factor is the level of immersion the users feel when experiencing the VE, also called presence. As an important part of experiments in VR is to make the users feel like they are actually experiencing the environment they are in, the level of presence they feel might affect wayfinding performance. In order to be able to map the presence the users feel when performing an experiment in a VE, one need to take use of a questionnaire, which is used later in this thesis. This is more thoroughly explained in section 4.2.3.

There are not only human factors that have an affect on wayfinding in VEs, how the environment is modelled also has an impact. Environmental factors can be categorized into three; differentation, visual access and layout complexity (Weisman, 1981). The first factor, differentation, is about how different the elements in the environment look like. If an environment exclusively consists of buildings that look the same, this might affect wayfinding in the way that it is difficult to see distinct and memorable elements. The second factor is how easy it is to see various parts of the environment. If the user for example is able to see the whole environment most of the time, he can more easily orient himself as he has all the information available. The third factor is how complex the layout of the environment is, for example if it consists of a street grid that follows north-south and east-west orientation. A last environmental factor that can be taken into account is wayfinding aiding. As described in the section above, one can program aid into the VE, for example in terms of signs, which can improve wayfinding performance.

3.4 Level of Detail

LOD in 3D graphics is a concept of which the number of triangles rendered for an object is reduced as the distance from the camera increases (Unity Documentation, 2017). This makes it possible to show more information the closer to the objects the camera is and less information the farther away the camera is. In 3D graphics, objects are built up by triangles and polygons, making a correlation between the amount of triangles or polygons used and how realistic the object is. For example, if one was to look at an object with 1,000 triangles and an object with 1,000,000 triangles, the one with the highest amount of triangles would look the most realistic, because the LOD is higher. That is, more details are shown.

As LOD says something about how detailed the objects in the 3D scene can be, this concept has an important application in 3D graphics. It is important to render as few triangles as possible, while prevent losing to much information, in order to maintain the frame rate stable and prevent the occurrence of lags (Reddy, 1994). One typical application of LOD implementation is when having a 3D scene with terrain. It is not vital to render all of the triangles that the mountains in the background of the scene have, because they are far away from the camera and the user will not get a worse experience if the mountains do not look perfectly authentic. By the use of LOD and to improve the efficiency of the computations, the mountains are rendered with fewer triangles when the camera is far away, and more triangles when the camera gets closer. An illustrative example of how LOD work on a 3D object can be seen in figure 3.8. There, the rabbit to the left would be close to the camera and the rabbit to the right would be far away from the camera in a 3D scene.

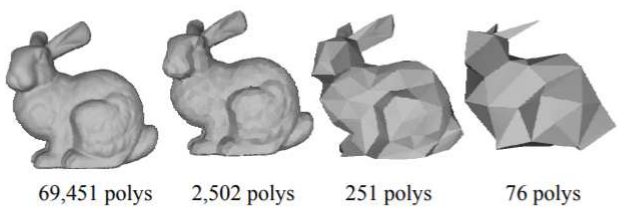


Figure 3.8: Objects with different LODs (Sunar and Zamri, 2008)

Chapter 4

Experiment

As this thesis ought to explore how the LOD of buildings impact human wayfinding, an experiment had to be conducted in order to obtain results to back up a conclusion of the research questions in the Introduction. The methodology behind making the VE and how the experiment was conducted is explained in this section.

4.1 Making the Virtual Environment

In order to make the VE the experiment was going to happen in, a developing framework had to be decided. At the time of writing there are multiple frameworks available for developing VR applications with Oculus integration. The frameworks include the following:

- Native (Mobile SDK), (Oculus Developers, 2020a)
- Unity, (Unity, 2020)
- Unreal Engine, (UnrealEngine, 2020)

As the time frame of the master thesis was limited, both Unity and Unreal Engine were tested based on an exploration of the best possible development framework. As the writer of this thesis had tested out and developed in Unity before, in his project work (Mortensen J., December 2019), the choice was made to use Unity version 2020.1 as the framework in this thesis as well. In Unity it is possible to develop by using both a modeling method and a scripting method, or a combination of both. By using Unity primitives like Cube, Square and Plane one can model a lot of the VE without any use of coding, just by using the properties of the primitives so one can set the position, rotation and scale. The scripting language of Unity is C sharp, often notated C#, which is useful for making alterations to the logic of the Unity prefabs and to implement other functionality.

In order to make Unity development compatible with the VR system Oculus Quest, an integration had to be made. Unity's Asset Store (Unity Asset Store, 2020a) provides several libraries and extensions, including Oculus Integration which "brings advanced rendering, social, platform, audio, and Avatars development support for Oculus VR devices and some Open VR supported devices" (Unity Asset Store, 2020b). This makes it possible to import assets into Unity that contain the functionality that has the role of the camera and movement logic in the VR system. The most used assets in the integration are the ones found in the Assets/VR/prefabs folder, in this case OVRPlayerController, which again contains OVRCameraRig. "It includes a physics capsule, a movement system, a simple menu system with stereo rendering of text fields, and a cross-hair component." (Oculus Developers, 2020b), which makes it the most essential component in the VE. It uses the OVRCameraRig to replace the camera in the Unity application and has the functionality of showing the scene in the HMD of the Oculus. Since OVRPlayerController includes a physics capsule and a movement system, one can model it to make it possible for the user to move around in the virtualized environment, by for example walking on top of a ground object.

One problem in VEs can be the interaction with other elements in the environment. As one is dependent on for example walking on a surface and not be able to walk through buildings, some of the objects in the environment had to be altered. In order to fix this, Unity has group of components called colliders (Unity Documentation, 2020). These makes it possible to detect when collisions between different objects occur and thereby preventing the objects from intersecting each other. The following properties were given to the objects in the VE:

- Mesh Collider - In order to match the shape of the complex mesh of the 3D buildings, a mesh collider component was given to the building objects. This made it possible to walk close to the buildings, but never through them.
- Rigid Body - For the OVRPlayerController to function similar to a human being, a rigid body component was added to the object. This made it possible to detect collision between the person in the VE and the mesh collider component of the buildings.

Another important property that had to be configured was the radius of the OVRPlayerController. For the OVRPlayerController to move between the buildings and not detect collision to far away from them, the radius had to be small enough so that it could fit between all of the buildings without colliding with them. By trial and error, the radius was set to 0.02, equal to the height of the OVRPlayerController such that it eyes were above the ground and not staring into it.

Along with the modeling done for setting up the VE with Oculus integrated, some scripting also had to be done in order to facilitate the starting of different tasks in the application. More information about the tasks are given in section 4.2.1. As there were four different tasks made, an UI Manager had to be made for the menu to navigate between them. A positive effect of this could be effectiveness and simpleness of the execution of experiment. By making a menu user interface, and making a script that made different OnClick-events for each button, only the scene with the respective task was loaded, making it fast to start a new task after a finished one. In figure 4.1 the menu user interface is shown.

Figure 4.1: The menu user interface with the buttons for starting the different tasks, screenshot from Unity

Circumstances with the COVID-19

Because the circumstances with the COVID-19, the development of the VE described above were done along with testing of the environment inside Unity's game view. As the university campus was on lockdown and the Oculus Quest was located at campus, it was not possible to use the system for a period of six weeks. This means that the VE had to be developed to fit how it would look and work like when emulating VR on a Windows computer, that is without actually being able to test the environment on a real VR system until a very late stage of the thesis. Because of this, several simplifications had to be made in order to be able to build the application such that it was compatible with the Oculus Quest. The main functionality of the OVRPlayerController and the VE were the same as before, but the main simplification that was done was removing the menu and the instructions button. As buttons work differently in VR due to the need of pointers, these were removed. A simplification for the menu was to create an application for each of the tasks, resulting in a total of eight applications instead of two applications (low LOD and high LOD). How the problem with the instructions button was solved is written more about in section 4.2.1.

4.1.1 Choice of Model Environment

As this thesis aims at exploring how the LOD of buildings affect navigation, an important aspect of the experiment was to find a suitable environment, with a suitable area for the building architecture. The choice between creating a fictional area and a realistic area was made, where the efficiency of the development process was the biggest decisive factor. If one was to choose the fictional area, one would have to create all the buildings manually and get the LOD high enough for the buildings to be at a complex level which would be more inefficient. However, one would get the opportunity of creating an area entirely at one's own request, which can be important in experiments where one want to explore very specific topics, like in this thesis' case. Making a realistic area, on the other hand, would make the development process more efficient as there are software and applications available that can do a lot of the development. The issue about this solution is to find an area with a suitable building architecture. For the experiment in this thesis, there was a number of criterias that had to be fulfilled if a realistic area was to be made.

- Building architecture data available
- Unknown area for the participants
- Large enough scale
- Quadrant-based, grid planned streets ("Kvadratur")
- Minimal elevation differences

As for the first criteria, a good choice would be to use the 3D application 3D Clip & Ship (Geodata, 2017). They have building data covering a big part of Norway in 3D model format which can be extracted and imported into Unity. Therefore, by choosing an area in Norway, this application could be used in order to get an efficient development process. As for the two next criterias, big cities like Oslo and Bergen, and small villages would not do the trick, as a lot of people are familiar with the biggest cities and there aren't enough building architecture in the small villages. Thus, a medium sized city would be a possibility. As for the fourth and fifth criterias, the options are rather limited due to the fact that not many cities in Norway have the desired architecture. Oslo and Kristiansand are the two cities in Norway with known quadrant-based architecture (Butenschøn P., 2019) that could suit this experiment and therefore the chosen area would have been the city Kristiansand, which has a lot of area that is quadrant-based and the elevation differences are minimal.

Based on the information above along with the fact that the writer of this thesis has had experience with extracting buildings from an area by using 3D Clip & Ship (Mortensen J., December 2019), the choice was made to use the application in this thesis as well. "Kvadraturen" in Kristiansand, which can be seen in figure 4.2, was the area chosen as the best suitable area for the VE. More information about how the development process was carried out can be found in section 4.1.2.

Figure 4.2: An overview image of Kvadraturen in Kristiansand (Google Maps, 2020)

4.1.2 Modeling the Buildings

An important part of the work of this thesis was to model the buildings that were placed inside the VE. As the main goal was to explore how the LOD affected navigation, each building was modelled in two versions; one with high LOD and one with low LOD. All of the buildings were given elevation equal to 0, as the terrain of the environment were not supposed to be used as a navigational aid. In the two upcoming sections, more details about how the modeling of buildings was carried out are presented.

High Level of Detail

As mentioned in section 4.1.1, the 3D application of Geodata, 3D Clip & Ship, was used in order to make the high LOD building models. With 3D Clip & Ship one can draw an area of interest, for example a square, triangle or by free hand, and extract the data that is correlated with the area, like 3D models of buildings and terrain data. This is extracted as a file geodatabase, which can later be used in order to be imported into Unity as 3D models. Thus, by drawing the area of interest, in this case Kvadraturen in Kristiansand, the file geodatabases with building data were exported. Figure 4.3 shows the application after the area of interest were drawn.

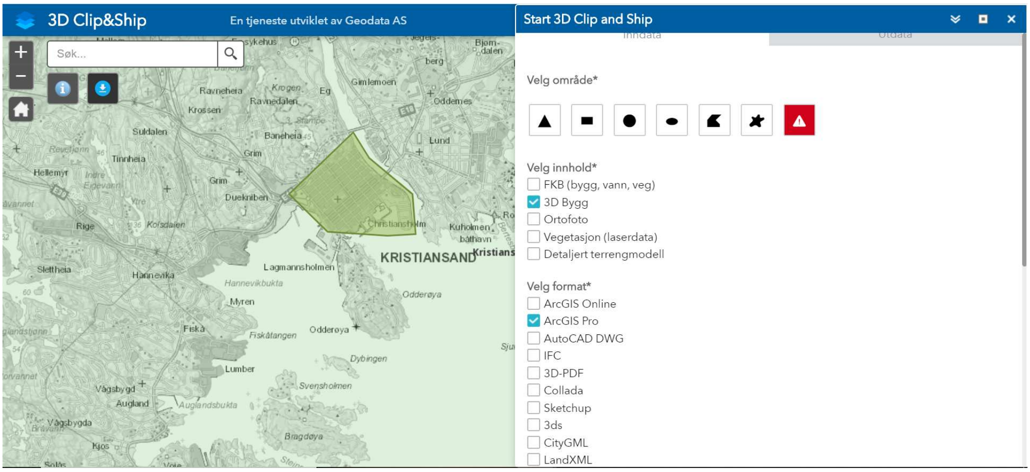


Figure 4.3: The area of Kvadraturen drawn in the web site application 3D Clip & Ship

After extracting the file geodatabases from 3D Clip & Ship, one has to convert the data into a format that Unity support, such as .fbx or .obj (Unity Docs, 2017). By using this information and from previous knowledge of the author of this thesis, the choice of using the advanced 3D design software CityEngine, developed by ESRI (ESRI, 2020), was made. This software makes it possible to import the file geodatabases as 3D models, visualize and modify them. By aligning all the 3D shapes to the terrain that has elevation equal to 0, an export had to be made. Since both CityEngine and Unity supports .fbx files, the 3D models were exported to this format so they were ready to be imported into Unity. This workflow made it essential to do all of the modification of buildings in CityEngine, so the only alterations that could be done in Unity were related to position, scale, rotation and coloring. The result after the import has been done into Unity can be seen in figure 4.4.

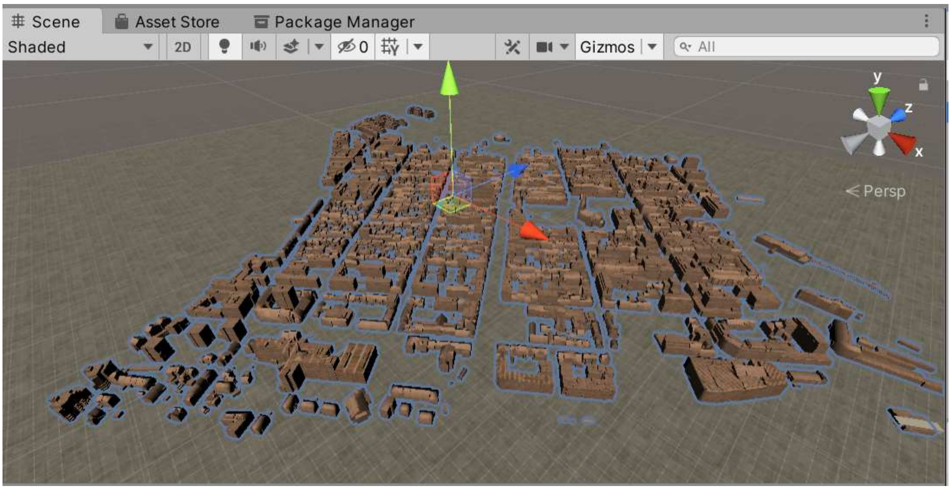


Figure 4.4: The city model of Kvadraturen with high LOD, screenshot from Unity.

Low Level of Detail

In order to create the low LOD city model, two different approaches were explored. As both Unity and CityEngine already had been taken into use during the modeling phase, these were the two softwares tested out. Due to the experience of the author with both softwares, a choice was made regarding the effectiveness of the task, concluding that CityEngine was the most effective choice of software. As the exported data from 3D Clip & Ship contained a set of footprints for each high LOD building, one was able to work with these in order to create the model fast and efficient. By extruding the two-dimensional footprint shape, one was able to copy the high LOD buildings' positions and create the buildings in low LOD by manually extruding them to the height of the high LOD buildings. Some manually alterations of the footprints had to be made, because some of the buildings were atypical and not suitable for extrusion from the buildings footprint. A screenshot from Unity after the low LOD model was imported can be seen in figure 4.5.

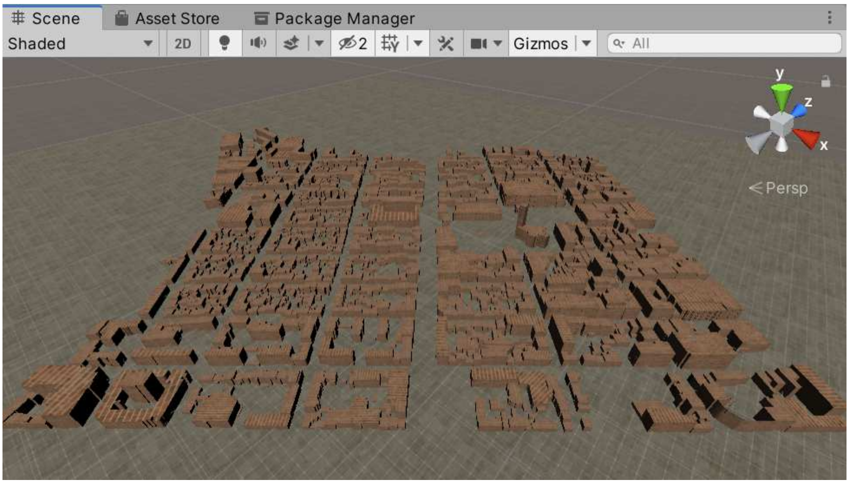
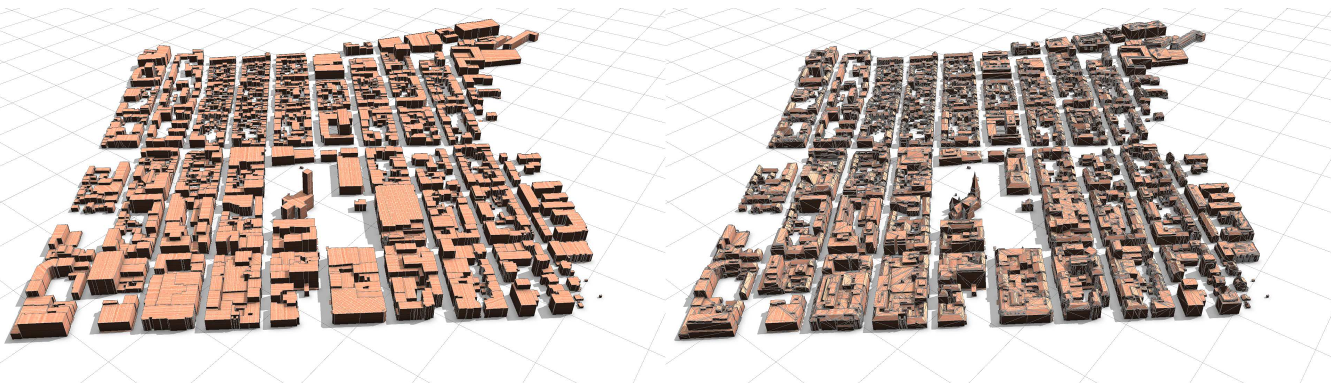


Figure 4.5: The city model of Kvadraturen with low LOD, screenshot from Unity.

Model Differences

In order to show the difference between the two different LOD models, some visualization and quantitative data will be presented. Both city models have been given the same texture, such that the only thing that differs between the models is the LOD. The screenshots have been taken in CityEngine as the background was white and the buildings could easily be seen.



(a) Low LOD City Model

(b) High LOD City Model

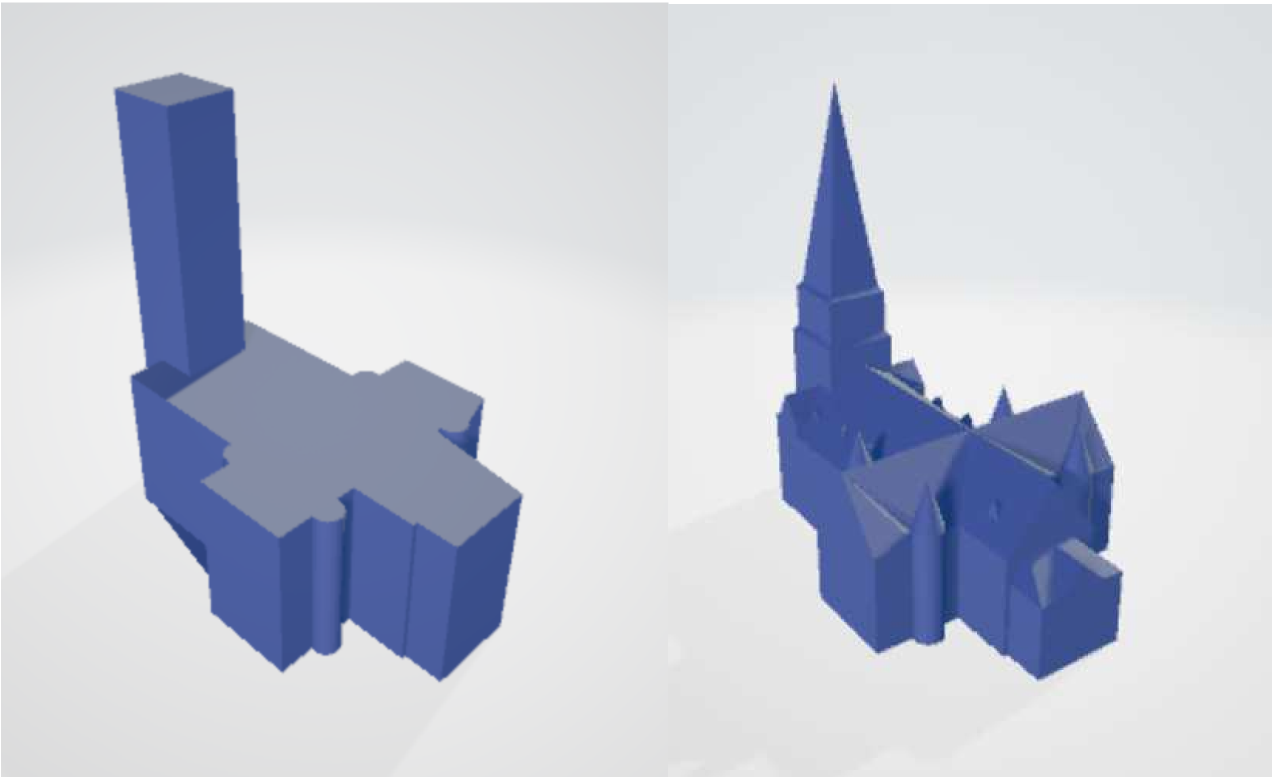
Figure 4.6: The two city models, screenshot from CityEngine

	Low LOD	High LOD
Number of buildings	2255	2326
Number of polygons	20712	156777
File size	1052 kB	1425 kB

Table 4.1: Properties of the two different city models

From table 4.1 and figure 4.6, there are some clear differences between the city models. The reason why the number of buildings differed, was that some of the building shapes inside the quadrants were not able to be extruded and therefore the high LOD model has a bit more shapes. However, the important number to consider from table 4.1, is how the number of polygons differ. The number of polygons in the high LOD model is over seven times more than in the low LOD models, which makes the former much more detailed. This can clearly be seen in figure 4.6 by looking at the grey polygon lines that shapes the models. More polygons means that more details can be shown, which again means that it can be easier to resemble real life buildings.

To give an example of a building which differs a lot in the city model, the church in the center of the city can be used to visualize this. Figure 4.7 and table 4.2 give visualization and quantitative data.



(a) Low LOD Church **(b)** High LOD Church

Figure 4.7: The two church models

	Low LOD	High LOD
Number of buildings	1	1
Number of polygons	73	676
File size	24 kB	35 kB

Table 4.2: Properties of the two different church models

The church contains a lot of details, making it hard to model with few polygons. This can clearly be seen in figure 4.7, where the resemblance of a real church is really bad in the left sub figure, and much better in the right sub figure. A good resemblance of buildings may lead to improvement in wayfinding performance in VR, by having a more clear cognition of an actual church. In the city model created, the church is a good example of how important LOD can be when talking about visual cognition of buildings.

4.2 Experiment Design

To be able to conduct a good and reliable experiment, the experiment has to be designed such that it targets the research questions of this thesis by giving quantitative results which can be used as input in a statistical model. In the experiment design process the following had to be decided:

- Approach - How should the experiment be conducted?
- Goals - What should the goal of the experiment be?
- Result metrics - What metrics should be measured in order to give a clear image about the result of the observations?
- Statistical metrics - Which metrics should be included into the statistics?

In the two upcoming subsections these questions about the experiment design will be answered.

4.2.1 Methodology

In order to create and design the experiment, different approaches were thought of and explored. One possible approach was to design a course through the city model, making the participants navigate from A to B by using text-based instructions. As a helping aid a map could be implemented such that the participants did not get lost and their observation ruined. However, due to the fact that this thesis aims to explore how different LOD of buildings affect wayfinding, this approach would not be sufficient. The fact that the map could aid the participants and serve as a navigation tool as well as the fact that the participants could navigate by the use of street patterns, such as counting the amount of cross section from A to B, would weaken the goal of the experiment and therefore had to be discarded.

As the buildings of the city model should serve as the only aid in navigation, the following approach was explored. By giving a combination of text-based and image-based instructions, the participants could be given a number of wayfinding tasks that had to be completed. An example of the instructions could be for example: ”Turn right after building A is passed, turn left when building B is one your right hand”, where building A and B were illustrated by an image from the real world, for instance from Google Street View (Google, 2020). This would make the participants use only the buildings of the city model to navigate and one would get clear results if the LOD affected the wayfinding, by testing if the cognition of the 3D buildings were sufficient enough to recognize the real world buildings. By making several smaller tasks, more observations could be conducted and give more comprehensive results. A more thorough explanation of the tasks is given in section 4.2.1.

Plan

To be able to carry out the experiment as structurally and thoroughly as possible, a plan was made which showed the steps the participants had to go through. The plan applied to every new participant and consisted of the following steps:

1. Participant gets verbally informed about the purpose and goal of the experiment. Information about the VE remains unknown.

2. Participant gets informed about potential motion sickness due to the fact that an observation may be aborted if the illness occurs.

3. Participant fills out a questionnaire about spatial abilities. The questionnaire can be found in appendix B.

4. Participant gets to know the VE system Oculus Quest. The HMD gets adjusted so it fits the participant's head and the participant gets guided around in the menus and tests the joysticks to get a feeling of how to control in the environment.

5. Participant gets the text-based and image-based instructions and reads them. The participant will also have the option of seeing the instructions while doing the experiment run.

6. Participant conducts the experiment trying to solve the task the quickest way possible.

7. Participant fills out a questionnaire about presence. The questionnaire can be found in appendix C.

Tasks

In order to obtain a fair amount of observations in the trial run, several tasks had to be made. As the VE consisted of buildings in a quadrature architecture, a natural amount of tasks would be four. With the use of four tasks, one would be able to make sure that the exploration of the city model would be different for the participants in each task, meaning that they would not explore the same area for different tasks. By making sure that the starting points of the tasks were located on each side of the quadrature, a big part of the city would be explored, which is positive when trying to see an indication whether or not the LOD affects the wayfinding. In figure 4.8 the starting points of each task are marked, along with the respective letter of the task the starting point belongs to. For all starting points, the orientation of the HMD in the VE were set such that they pointed towards the center of the city.

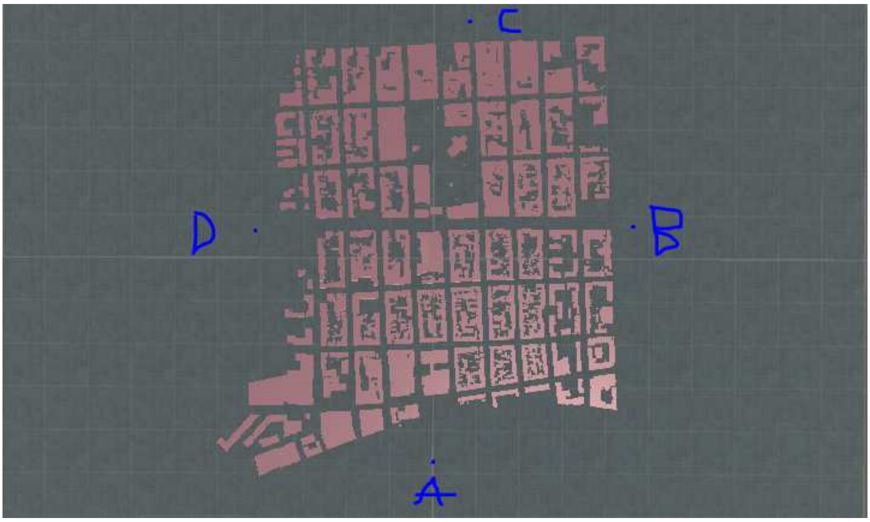


Figure 4.8: The starting point for the four different tasks in the VE, screenshot from Unity

In order to make the different tasks, different variables were taken into account. The distance from starting point to destination, the complexity of wayfinding, that is how difficult it is to relate the buildings on the route to the ones given in the instructions, and how easy it is to spot the object one is looking for. With those variables in mind, all of the tasks were made such that they differed from each other.

There was made a total of four tasks, respectively task A, B, C and D. The starting point of each task illustrated in figure 4.8, one starting point on each side of the city model. The tasks were given as both text-based and image-based instructions that were given to the participants before they conducted their wayfinding task. As instructions are difficult to remember, especially images, the participants had the possibility of seeing the instructions in the middle of their run, while the amount of times they had to look at the instructions was registered. The instructions gave the participants directions about which direction they should go along with pictures of the buildings around the turn points. By looking at the images given in the instructions, the participants could compare them to the VE and try to figure out where to make turns, in order to find the destination. The destination of the task was marked in the VE by a yellow sphere, which the participants had to bump into in order to complete the task. The tasks made can be seen in appendix D. In figure 4.9, a screenshot of the ”Instructions” help function in Unity is shown.

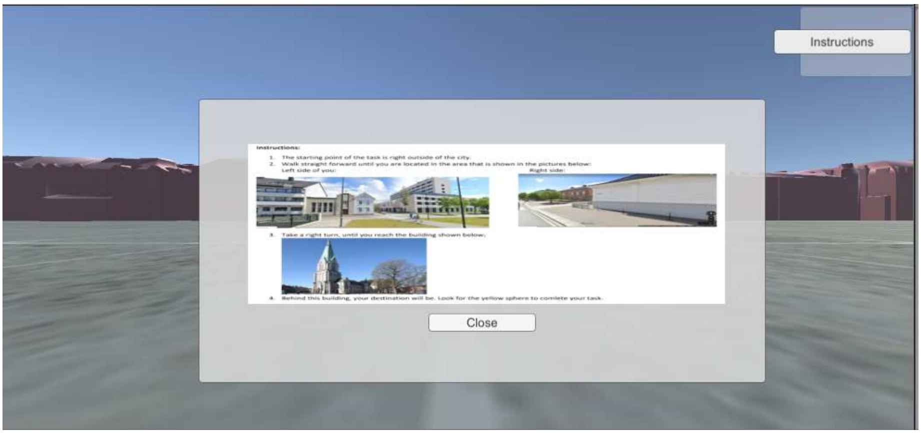


Figure 4.9: The Instructions popup that was supposed to be available for the participants, screenshot from Unity.

The task instructions were worked out by choosing a route from the destination to the origin, and the turns that had to be made were mainly done in intersections. In the intersections, Google Street View was used to find pictures of how the buildings around the intersections looked like, and screenshotted into the task document. A big problem with Google Street View is that there is not possible to choose what elements that should be shown. For example, Google Street View shows a lot of people, trees, signs and other elements that are not relevant for the experiment of this thesis, making it difficult to find an optimal picture. The only workaround possible would have been to either take pictures of the intersections manually, by traveling down to Kristiansand and take snapshots, or use an image manipulation program to filter out the unwanted elements. For the scope of this thesis, none of these workarounds were used, but the most suitable picture of the buildings in Google Street View were chosen for the image-based instructions.

As written in section 4.1, COVID-19 affected the development process of the application, with a great lack of testing towards the Oculus Quest during development. This affected not only the development of the VE, but also the development of task instructions. As written above, the original plan was that the participants could have the possibility of pressing a button to show the instructions in front of them. However, this had to be simplified, due to the combination of text-based and image-based instructions, and that it was difficult to show the instructions for the user in a simple manner in the Quest. Hence, by removing the instructions button and instead giving the participants the opportunity of looking at the instructions outside of the VE, that is having the instructions in front of them on a computer by taking off the HMD, this functionality was simplified. The problem with this solution is that it will not run as smoothly as it would in the upper case and that the wayfinding will take longer time due to the removing of HMD. However, this will be taken into account when looking at the results of the wayfinding, by registering the amount of times they have to look at the instructions.

4.2.2 Result Metrics

An important aspect to consider when designing an experiment is what metrics to measure from the observations. One wants to use the metrics that gives a clear picture of the observation and indicate that a better performance of one observation gives a better measure of its metrics. In order to obtain the goal of the experiment, which is to explore if the LOD affects wayfinding, metrics had to be chosen that target wayfinding performance. As this thesis concerns wayfinding and navigation, the following are three examples of metrics used for wayfinding tasks (Ruddle and Lessels, 2006):

- Task performance
  - Time used completing the task
  - Distance traveled when completing the task
  - Numbers of errors made during the task
- Physical behaviour
  - Locomotion
  - Looking around
  - Time and error classification
- Decision making
  - Think aloud
  - Interview
  - Questionnaire

For the purpose of this thesis, metrics that aim to give quantitative data were required. In order to give a clear overview of the differences between the observations in low LOD and high LOD, time used completing the task was the primary metric chosen. By this, it was possible to measure the time taken by the participant from the start of the navigation until they reached their destination. In order to give an indication on whether or not one made more errors when navigation in low LOD or high LOD, secondary metrics regarding numbers of errors made and the number of times the participants had to look at the instructions during the task were also taken into account. In addition to the quantitative metrics, the participants would also be encouraged to think aloud, that is talk through the wayfinding process. After the run was conducted, the participants would also be interviewed about how they felt while navigating, such as the difficulty, length of the task, if they had any specific problems in some of the intersections and so on.

4.2.3 Questionnaires

In order to get additional data regarding the navigation in the VE, two questionnaires were made and given to the participants to answer. By having these data, one could get indications if for example the participants were skilled in navigation or if they felt bad presence in the VE, making it more difficult to navigate properly.

Spatial Abilities Questionnaire

An important aspect to consider when conducting a wayfinding experiment is how skilled the participants are in navigation, or their spatial abilities. If for example a person completes a navigation task in the experiment fast, one would not know if the participant's navigation skills caused the fast completion or if it was the task environment. In the case of this thesis, if one saw a significant reduction in completion time for the high LOD model, this might be correlated to the navigation skills of the participants. Hence, it is important to have a quantitative estimation for the participants' spatial abilities.

Measuring spatial abilities is somewhat of a complicated task, as there is not any single objective attribute about a person that indicates whether or not the person is capable of navigating well. As there are different aspect to consider regarding spatial abilities, Hegarty et al. (2002) proposed a method which uses a self-report scale method, called the Santa Barbara Sense of Direction Scale (SBSOD). The SBSOD is reported doing better when the tasks consist of self-motion and orienting oneself in the environment, which is what the experiment in this thesis aims to do. The SBSOD consists of a questionnaire of 15 statements, each scaled from 1 (strongly agree) to 7 (strongly disagree), where 4 is neutral and the higher SBSOD score, the better spatial abilities one have. In order to calculate the score, first one has to adjust for positively phrased statements, as the score only yields for negatively phrased statements. By taking the total score of the answers and dividing it with the amount of statements, one will obtain the SBSOD score. The entire spatial ability questionnaire can be seen in appendix B.

Presence Questionnaire

As the experiment in this thesis was set in a VE, it is important to know information about how the participants felt while experiencing the VE. For instance, if a majority of the participants felt a lack of presence in the VE, that could be an indication of a badly modelled environment, which could lead to a loss in interest and a decrease in performance. Therefore, the participants answered a presence questionnaire after they conducted their first run in the VE. The presence questionnaire used was made by Slater et al. (1994). As the VE in this thesis was made without having fully realism in mind, in order to highlight navigation with only buildings as aid, the results of the questionnaire cannot be looked at conclusively. However, it might give an indication whether or not the participant felt immerse in the environment.

The questionnaire consists of five question, all of which use a scale from 1 to 7 as answers. In order for the participants to explain thoroughly how their experience was, they also had the possibility of explaining in words if they wanted to notify more about any aspects of the VE. The questionnaire can be seen in appendix C.

4.3 Execution

The original plan of the experiment was to first conduct a trial run with a small amount of participants, approximately five persons, and gain experience from the trial regarding length and difficulty of tasks, the look of the VE and other aspects. After the trial run was conducted, a bigger amount of persons would be included in the final experiment, having between 20 and 30 people conducting runs. By having a large amount of persons conducting runs, more could be interpreted from the statistics and results would be more conclusive. However, due to the situation with the COVID-19, the final experiment had to be discarded from the thesis. From talks with the supervisor, the author of this thesis decided that it was irresponsible gathering several people in the same room and especially encouraging them to wear the same HMD. Therefore, following the recommendations of Norwegians Institute of Public Health (Folkehelseinstituttet, 2020), the experiment was conducted as a trial by having the author of this thesis' roommates as participants, where all of them were students at NTNU. There was a total of four participants in the trial, two women and two men and the average age of the participants was 24.

The trial followed the steps explained in section 4.2.1. The participants were given the opportunity of using the Oculus Quest for quite some time and using different applications to familiarize themselves with VR and get used to the immersive feeling. As motion sickness has a tendency of occurring when using a HMD, the participants were encouraged to make slow rotations and abort the trial if starting to feel ill. In order to make further inspections of the trial afterwards, video recordings internally in the Oculus Quest were captured . By this, there was possible to see if there was any difficult intersections or part of the task that was difficult to understand.

The trial was conducted in week 22 in year 2020, in the residence of the author of this thesis, in Trondheim. As the COVID-19 was still active, the controllers and HMD were cleaned thoroughly before and after each participant had conducted their run. The Oculus Quest was connected to a computer such that the author of this thesis could keep track of the participants' progress and see how they navigated.

Figure 4.10: *Jørgen Mortensen, "A participant of the trial using the Oculus Quest to navigate in a virtal environment", May 26 2020*

Chapter 5

Results

In the following chapter, the results of the experiment trial will be shown. There will be shown a comparison between the low LOD tasks and the high LOD task in order to get a clear picture of a possible significant difference between the two LOD models. In addition, some of the answers from the after-trial interviews with the participants will be shown, in order to gain knowledge about positive and negative sides of the trial.

All the results from the trials can be seen in appendix A. Some of the key values from the results can be examined in table 5.1. In the table, the results have been categorized into ”low LOD” and ”high LOD”, in order to see a difference between the two. As it was only a trial run with few observations, there would not make any sense to show the results of each of the specific tasks, as there were only two observations per task. The ”Mean completion time” row denotes the average of the total time the participants spent completing tasks in each of the two city models. The ”Instructions shown” row denotes how many times in total the participants had to look at the instructions in order to be able to navigate further on in each of the city models. The ”Errors made” row denotes how many errors were made in total by the participants in the two different city models.

	Low LOD	High LOD
Number of observations	8	8
Completed tasks	6	7
Mean completion time, t	369,4	413,5
Instructions shown	57	40
Errors made	10	6

Table 5.1: The key values obtained from the results of the trial

Two of the runs in low LOD were aborted due to the fact that a participant felt ill from simulator sickness after having made an error and trying to recover back to the original starting point, and one of the runs in the high LOD was aborted because a participant got completely lost and was unable to recover back to the starting point. During one of the runs, the Oculus controllers had trouble connecting with the HMD, making it impossible to use the joysticks to navigate. However, they got reconnected after removing and putting the batteries back in and therefore the participant could continue his run. The time spent on fixing the controllers was subtracted from the time it took to complete the task.

5.1 Statistics

In order to be able to answer the research questions in the Introduction, there is a need to establish if there exist a significant difference between the two data sets obtained from the experiment, respectively the low LOD data set and the high LOD data set. Because of the circumstances with the COVID-19 and the implications described in section 4.3, the statistical analysis that should have found if there existed a significant difference in the data sets was not possible to conduct beyond the few data points that were gathered in the trial experiment. Therefore, in the upcoming section a theoretical approach of the statistical analysis will be explained, as well as a correlation test will be shown where the data from the trial is used.

5.1.1 Probability Distribution

The first thing that has to be done when performing a statistical analysis is to determine the probability distribution the data sets may match. As the data set sizes obtained from the trial are very low, that is a maximum of two data points in each of the eight LOD-task cases, it does not make sense to find a matching probability distribution in that case. Generally, when trying to find a distribution, one can plot the data points in a histogram or in a Q-Q Plot (Ford, 2015). By visual inspections, one can get an indication of what type of probability distribution the data points fit and take possible outliers into consideration, depending on the data points. As visual inspection can be unreliable, there should also be done a significance test by creating a null hypothesis stating that the data set is drawn from a certain distribution and an alternative hypothesis stating that it is not. In case of normality, that is the data set is drawn from the normal distribution, several powerful normality test have been worked out (Shapiro and Wilk, 1965; Anderson and Darling, 1954; Massey, 1951). As the sample size of the trial in this thesis is a maximum of two data points for each combination of LOD and task, it does not make sense to test how the data points fit any distribution.

5.1.2 Significance Test

After the data points from the trial have been fitted to a probability distribution, a significance test can be used in order to determine whether or not the low LOD and the high LOD in each of the four tasks are significantly different from each other. In order to use a significance test, first it needs to be constructed two hypotheses:

$$H_0 : \mu_{Low} = \mu_{High} - \text{Sample sets are not significantly different.}$$

$$H_a : \mu_{Low} \neq \mu_{High} - \text{Sample sets are significantly different.}$$

There are a numerous different significance tests that are able to test sample data sets with each other, but the applications of the tests depends on the probability distribution the sample is fitted to. Therefore, a difference has to be made between normal and non-normal probability distributions.

Normality

If one assume that the data set sample is drawn from a normal probability distribution, one can use a Student's t-test. The Student's t-test works well when the normal distributed data sample size is low and the true value of the standard deviation is unknown. It works by setting a significance level, for example 5%, which gives a 95% confidence interval. That is, we can be 95% sure that the hypothesis chosen will be the correct one.

In the case of the data set obtained from the experiment, if it had not been for the circumstances of the COVID-19, a two-tailed Student's t-test would be chosen to test for significance, assuming that the data set was similar to a normal distribution. There would be conducted four Student's t-tests, in order to test the significance between low LOD and high LOD for each of the four tasks and if the p-value from the tests would prove to be higher than the significance level, the null hypothesis in that respective test would be accepted. A Student's t-test could have been used in order to generate a result from the trial runs, but this would not give any indication whether or not the data sets were significantly different due to the low sample size.

Non-normality

If the data set sample is drawn from a non-normal probability distribution, the Student's t-test is not applicable, particularly if the sample size is below 20. In order to test the significance between two data samples one can take advantage of a non-parametric test, where no assumption about the distribution type is made (Statistics How To, 2020). If the case was that the data from the experiment had been non-normal distributed, tests like Wilcoxon Signed Rank test or the Mann-Whitney U test could have been used (Woolson, 2007; Mann and Whitney, 1947).

5.1.3 Correlation

In order to gain information to answer research question 2, if spatial abilities and level of presence affect performance in wayfinding tasks in low LOD models and in high LOD models differently, the correlation between the different data sets obtained in the trial can be calculated. Although a possible correlation may be found between some of the data sets, this can only give an indication, not an implication. Regarding wayfinding performance, three different metrics have been measured for each participant in both low LOD and high LOD; Time used for completing the tasks, instructions used and navigational errors made. The statistical correlation will be calculated between these data sets and the participants respective SBSOD score and presence questionnaire score. The correlation coefficient calculated is a number between -1 and 1, where -1 denotes total negative correlation, 0 denotes no correlation and 1 denotes total positive correlation. As the data set sizes are very limited, the significance level of the correlation coefficient will not be calculated, as it would not give any valuable information anyway. Microsoft Excel (Microsoft Corporation, 2019) was used for the statistical calculations and the results are shown for SBSOD correlation and for presence correlation, in table 5.2 and table 5.3 respectively. The mean completion time denotes the mean completion time for each participant in each of the models.

	SBSOD - Mean completion time Correlation	SBSOD - Instructions Correlation	SBSOD - Errors Correlation
Low LOD	0,841	0,046	0,565
High LOD	0,030	-0,41	0,225

Table 5.2: The correlation between SBSOD and the three metrics obtained from the trial, for both low and high LOD.

	Presence - Mean completion time Correlation	Presence - Instructions Correlation	Presence - Errors Correlation
Low LOD	0,405	-0,458	0,025
High LOD	0,301	-0,252	0,408

Table 5.3: The correlation between presence and the three metrics obtained from the trial, for both low and high LOD.

The correlation coefficients calculated must be interpreted with great caution. As each of the participants only had a maximum of two runs in each model, the size of the data sets are far too low. Additionally, when interpreting the coefficient, one needs to think about the fact that a positive coefficient means that the higher SBSOD and presence score, the higher mean completion time, instructions shown and errors shown, which is actually negative and an indication of bad performance.

5.2 Qualitative Participant Data

The participants' thinking aloud during the runs along with the interview that was conducted after the trial runs, generated a number of qualitative data which can explain what affected the wayfinding in the VE. The following statements were taken from some of the comments that were obtained from the participants:

- They thought it looked different on the instruction pictures and in the VE. The depth, that is the distance between the user's perspective and the buildings, was totally different and made it difficult to comprehend how far away buildings were from each other.

- They often forgot where they had turned, which made errors resulting in aborts of some of the runs.
- They thought it was difficult to compare a VE consisting of buildings to pictures that were taken from the real world, with cars, trees and other elements.
- They thought the city felt very artificial because buildings outside the quadrature was removed. It felt weird when walking past a building and suddenly there was nothing behind it.
- They thought some of the modelling was bad and gave a bad image of how the real world looked like, for instance there was modeled a very low building where there was actually a parking lot in the real world.
- The perspective they saw in the VE was different than the perspective the buildings were pictured from.
- Because all buildings had the same texture made it confusing, especially when the instruction pictures had their original texture.
- The only reason they turned around after they made a mistake was because the city ”ended”.
- They tried to see distinct features, such as posts and special architecture. When these were left out of the buildings in the VE it got really difficult.

5.3 Spatial Abilities Questionnaire Results

The participants were asked to fill out the spatial abilities questionnaire before the experiment, so it could be seen if there existed a connection between the participants spatial abilities and their performance in the experiment runs. As explained in section 4.2.3, the questionnaire gives a SBSOD score, which is a number between 1 and 7, where the higher the score, the better one's spatial abilities is.

The mean SBSOD score was 4,4 with a minimum of 3,6 and a maximum of 4,9. All of the participants used almost the whole scale, that is all had at least six different answers on the 15 questions. Question number 1, which stated ”I am very good at giving directions” had the highest average score with 5,25 among the participants, while question 3 and 10, ”I am very good at judging distances” and ”I don't remember routes very well while riding as a passenger in a car”, respectively, had the lowest average score with 3,25.

5.4 Presence Questionnaire Results

The presence questionnaire consisted of five questions, each of which using a scale from 1 to 7, where 7 indicated the highest level of presence. The average mean result of the presence questionnaire was 4,2 with a minimum of 3,6 and a maximum of 4,8. It was commented by the participants with video games experience that they felt less presence, because they were used to the concept.

There was a feeling among the participants that the questions were very much related to each other, making it difficult to differ them apart in the sense they were meant. Therefore some of the participants did not really think through what they answered. Two of the questions sounded ”During the time of the experience, did you often think to yourself that you were actually in the VE?” and ”Please rate your sense of being in the VE from 1 to 7”. Although all of the participants felt like these two questions were the same, everyone answered differently, with a mean score of 4,0 on the former question and a mean score of 4,75 on the latter.

The question that had the lowest mean score was question number 3, which sounded ”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?”. Here, the participants commented that the fact that they needed to take of the HMD in order to see the instructions decreased some of the level of presence they felt.

Chapter 6

Discussion

In this thesis, an experiment trial consisting of four participants has been conducted. The goal of the trial was to explore whether or not the LOD of the city model affected wayfinding performance. Due to the circumstances of the COVID-19 virus it was not possible to obtain enough people for an experiment with 20 to 30 people, which is why only a trial was able to be conducted. This affected the results in a great manner, which is a reason why the results cannot be considered as conclusive. What was found in the results was that the number of completed tasks was marginally higher in the high LOD than in the low LOD, with 7 against 6. The number of times instructions were shown to the participants and the errors made by the participants was substantially higher in the low LOD than in the high LOD, 57-40 and 10-6, respectively. This results might give an indication that it was easier to navigate in the high LOD, with instructions more similar to the VE. Comments from the participants also indicate the same, for example some of the participants commented that they used distinct features from the picture of the buildings to navigate in the VE. As the low LOD model did not contain many distinct features, it is natural to think that this affected both the number of times instructions had to be used as well as the errors made. The mean completion time of the tasks in the trial indicate the opposite of what the other metrics do. The runs in the low LOD model were completed faster than the ones in the high LOD, with 369,4 secounds against 413,5 seconds. However, this number needs to be interpreted with very great caution. As both of one of the participants' runs in the low LOD model were aborted after taking a wrong turn and getting ill, the mean completion time of the low LOD model would probably be higher if there had not been for the simulator sickness.

The results obtained in the trial showed that the individual differences were substantial. For example in Task A in the low LOD model, there only two observations, whereas one of participants did not register a time due to simulator sickness. This means that it is very difficult to state whether or not it was the LOD that affected the wayfinding performance or if it was other factors. One important aspect to consider is that of video games experience. Previous research have indicated that frequent use of video games may increase wayfinding performance in VEs (Murias et al., 2016; Richardson and Collaer, 2011; Ventura et al., 2013). The interviews done with the participants after their runs showed that two of the participants frequently played video games. However, it is not possible to see a trend in the measured result metrics, as the observations are so limited.

Another factor that could be a subject for more exploring is the degree of presence the participants felt. Comments from the participants suggested that the presence they felt in the VE was reduced as soon as the had to remove the HMD in order to look at the instructions. They did not feel very immerse and they also revealed that the presence questionnaire was a bit confusing, and did not spend a lot of time thinking about what to answer. Therefore the correlation coefficients calculated cannot be considered as conclusive. The correlations vary a lot and it is difficult to see a trend. However, in the case of the amount of times instructions are shown, there exist a negative correlation for both low LOD and high LOD, meaning that the more times instructions was shown, the less presence was felt. This is expected, because the participants felt that taking off and on the HMD decreased the level of presence and therefore the two are negatively correlated. There exists no explicit trend on the difference between the low LOD and high LOD correlations, as it seems that in low LOD, mean completion time is more correlated, but errors made is less correlated. The results also reflect what has been found in previous research, as an example Nash et al. (2000) showed that there was not a clear indication that presence was correlated with performance. Therefore there is no evidence to support a hypothesis claiming that the level of presence affects performance differently in low LOD and in high LOD.

Previous research have shown that there exists a positive correlation between SBSOD and wayfinding task performance, meaning that better spatial abilities yield better wayfinding performance (Hegarty et al., 2002). The correlations between the SBSOD and the three metrics obtained from the trial in table 5.2 indicate that there exists a clear difference between low LOD and high LOD, when regarding how much spatial abilities affect the wayfinding performance. All of the three metrics have higher correlation with SBSOD in the low LOD than in the high LOD. This means that the better spatial abilities a participant had, the more time the participant spent on completing the tasks, more instructions were shown and more errors were made in the low LOD model than in the high LOD model. A reason for this might be because persons with higher spatial abilities may be used to navigating in the real world and therefore are used to having distinct features or maps to aid the navigation. By suddenly having to navigate in an environment with less distinct features and with bad LOD may cause confusion and lead to worse wayfinding performance. It is also important to notice that these results are conflicting to the ones known from previous research, as all of the correlations, except for the high LOD SBSOD-Instructions correlation, are positive. Therefore, together with the fact that the sample size is very low, the correlations have to be interpreted with caution.

The situation with the COVID-19 made the results that were possible to obtained from the experiment very limited. It resulted in conducting a trial, which originally was meant to provide insight in what could be changed in order to conduct a bigger experiment, with more participants. However, comments from the participants both from the think aloud during the runs and the interview after the runs gave some valuable insight in factors that might have impacted the results obtained. Previous research have suggested that there is a tendency to get lost more often when navigating in VEs than in the real world (Witmer et al., 1996), which can affect the performance a great deal. The experience from the participants in the trial was that when they first committed a mistake, such as a wrong turn, they struggled to get back to where they started as they forgot where they made the turn. This could possibly be solved by implementing an aid such as a map or by visualizing the path they already had went. However, as the meaning of the experiment was to only navigate using the buildings, this was not considered beforehand.

Another weakness of the trial was the mismatch between the buildings in the VE and the pictures in the instructions. As the pictures contained real-world elements, such as trees, persons and cars, it was difficult to focus only on the buildings. Additionally, the high LOD model should have been a total resemblance of the real-world buildings. Comments from the participants suggested that they navigated by the use of distinct features, but not all of the most specific features were included in the high LOD model. Therefore, a bigger difference in the LOD of the two models might have resulted in a bigger difference in the performance.

Chapter 7

Conclusion

This thesis has explored how buildings' LOD affect wayfinding performance and if the influence of spatial abilities and presence are dependend on the LOD. By developing two VEs, with different LOD of the buildings, a trial was conducted where four participants used a HMD in order to complete four different wayfinding tasks. Three performance metrics were measured; the completion time, number of times instructions were shown and the number of errors made in the navigation. Originally, there was meant to be conducted an experiment with a bigger sample size, but due to the circumstances with COVID-19 this was not possible to conduct.

The results from the trial cannot be considered conclusive, as the sample size was far too low. Additionally, the metrics differed in how the performance was in the two different VEs; while the time the participants used to complete the tasks was lower in the low LOD, the number of instructions shown and errors made were higher. In addition, the fact that three of the runs had to be aborted due to simulator sickness and as one of the participants got completely lost and therefore did not register a time has to be considered. The lack of possibility to get back to the starting point may have been a factor in the incompleteness of the three runs. As there has not been conducted a lot of research exploring the influence LOD has on wayfinding, it is difficult to compare the results with other experiments that have a larger sample size. However, from the comments of the participants, stating that they navigated by looking for distinct features on the buildings, which there exist more of in the high LOD model, it was expected that both the number of instructions shown and errors made were higher in the model with less details. Therefore, to answer research question 1, one can say that the trial gave a small positive indication that the participants performed better in the high LOD model, in terms of making errors and having to look at the instructions. The time spent completing the wayfinding tasks, on the other hand, can be regarded as worse in the high LOD model. As mentioned above, these findings have to be considered with great caution, as the sample size is very low and therefore the results are limited. By having a bigger sample size, a more statistical approach could have been used and maybe gotten more significant results.

Through two different questionnaires, the spatial abilities and the level of presence the participants felt during the trial runs were registered. These two factors were used in a correlation analysis against the three metrics in the trial, in order to answer research question number 2. There was an indication that the SBSOD score had more correlation with the metrics in low LOD than in high LOD. As the majority of the correlation coeffecients were positive, these findings go against previous research on the topic and should therefore be considered with caution. A bigger sample size is needed in order to perform a more thorough statistical analysis to get more conclusive results on this matter.

All of the results obtained in this thesis showed large individual differences. It got clear that using VR varies from person to person, and the participants performed very differently with it. In order to erase out the large differences, a bigger sample size had to be used in the experiment. Factors like navigational aid, such as a map that marks where one started, not needing to take the HMD off in order to see instructions and seeing where one performed turns, had to been explored more to get better and more conclusive results.

Chapter 8

Further Work

After exploring how different LOD affected wayfinding performance, no conclusive results were found. As it was only possible to conduct a trial with a very small sample size, the statistical analysis was weakened and no particular trend was seen. An experiment with a larger sample size, with over 20 or 30 participants, would have been interesting to carry out, as the statistical analysis of the results and conclusion would have been substantially stronger. There could also be developed more tasks, so the amount of runs per participant could be increased.

In order to gain more knowledge about how LOD affect wayfinding performance, there would have been interesting to include other real world elements in the VE. If elements like trees, landscape, cars and people were included, the participants could get a more immerse feeling and the wayfinding process would have been more similar to that of the real world. In general, a VR system contains most elements that are present in the real world, and to include most of these elements in an experiment would be useful. By exploring this, the developers would get knowledge about whether or not they could model the environment with lower LOD, that is fewer triangles or polygons, which can be important for optimizing performance.

As there was not used any particular navigational aiding in the experiment of this thesis, it could be interesting to see how the different navigational tools, like the ones described in section 3.3, affected the wayfinding process combined with the different LOD models. As a wayfinding process normally has some kind of aid implemented, this would be more realistic and also reduce the number of times participants had to abort the run due to getting lost.

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Appendix

A Results

In the column labels, abbreviations have been used so the table would fit the width of the page. ”L-A” denotes task A in the low LOD application, ”L-B” denotes task B in the low LOD application, whilst ”H-A” denotes task A in the high LOD application, ”H-B” denotes task B in the high LOD application and so on. Their cell values are the time it took to complete the respective task in the respective LOD in seconds. SBSOD is the score from the Santa Barbara Sense Of Direction test and PQ is the score from the Presence Questionnaire. The SBSOD and PQ cells are the mean value of the answers between 1 and 7 in the questionnaires, whilst the other cells consist of metrics in seconds. In the runs where the participant had to abort, due to either getting completely lost or feeling ill from simulator sickness, a hyphen, ”-”, is noted.

Id.	L-A	L-B	L-C	L-D	H-A	H-B	H-C	H-D	SBSOD	PQ
1	-		-			150		293	4,6	4,6
2	395		440			159		195	4,3	3,6
3		240		250	597		578		3,6	3,6
4		399		396	-		739		4,9	4,8

Table 8.1: Results from the trial and questionnaires

Table 8.2 shows the distribution of number of times instructions were shown to the participants.

	Low LOD	High LOD	Total number of instructions shown
Task A	20	13	33
Task B	11	5	16
Task C	15	15	30
Task D	11	7	18
Total number of instructions shown	57	40	97

Table 8.2: Instructions shown in the trial

Table 8.3 shows all of the participants' metric from the trial mapped to each participant. Mean time denotes the mean completion time in both LOD models in seconds. A hyphen, "-", is noted if no runs were completed. The "Instructions shown" denotes the number of times the each of the participants had to look at instructions and "Errors" denotes the number of errors made, aggregated in the respective LOD models.

	Low LOD			High LOD		
Id	Mean time	Instructions shown	Errors	Mean time	Instructions shown	Errors
1	-	14	2	221,5	4	0
2	417,5	21	5	177	8	0
3	245	11	0	587,5	15	2
4	397,5	11	3	739	13	4

Table 8.3: Participants' metrics data from the trial

B 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 a 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)

(Hegarty et al., 2002)

C 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 spac?

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)

(Slater et al., 1994)

D Tasks

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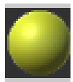
Task A

Goal of the navigation: Finding the yellow sphere, located somewhere in the virtual environment. By walking close to it, the navigation will finish and the task will be completed.



The task will consist of both text-based and image-based instructions. The instructions will also be available as help in the virtual environment, by pressing the «Instructions»-button in the top right corner. In order to navigate properly, you have to compare the buildings in the images with the ones in the virtual environment.

Instructions:

1. Start walking straight forward until you reach the intersection that looks like the image to the right.

2. Turn 90 degrees to your left in the intersection above and keep going forward until you reach the intersection that has the following building on your right:

3. Take a 90 degrees left turn when in the intersection above and move forward until reaching the area seen in the following image:

4. Take a right turn before the building in the middle and keep going forward until you reach your destination (the yellow sphere). It is looked on your right side along the path.

Instruction pictures obtained from Google (2020)

Master thesis – Navigation in Virtual Environments

Task B

Goal of the navigation: Finding the yellow sphere, located somewhere in the virtual environment. By walking close to it, the navigation will finish and the task will be completed.

The task will consist of both text-based and image-based instructions. The instructions will also be available as help in the virtual environment, by pressing the «Instructions»-button in the top right corner.

Instructions:

1. The starting point of the task is right outside of the city.
2. Walk straight forward until you are located in the area that is shown in the pictures below:
   Left side of you: Right side:

3. Take a right turn, until you reach the building shown below;

4. Behind this building, your destination will be. Look for the yellow sphere to comlete your task.

All pictures obtained from Google (2020)

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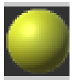
Task C

Goal of the navigation: Finding the yellow sphere, located somewhere in the virtual environment. By walking close to it, the navigation will finish and the task will be completed.



The task will consist of both text-based and image-based instructions. The instructions will also be available as help in the virtual environment, by pressing the «Instructions»-button in the top right corner. In order to navigate properly, you have to compare the buildings in the images with the ones in the virtual environment.

Instructions:

1. Walk straight ahead until you reach the intersection where the following buildings can be seen in the virtual environment in front of you

2. Take a left turn in the intersection above and continue down the road until you reach the intersection where you have the following buildings on your left side:

3. Take a right turn in the intersection and walk down the road until spot the destination of the task (the yellow sphere). Hint: It is found on the right hand before reaching the following building:

All pictures obtained from Google (2020)

Master thesis – Navigation in Virtual Environments

Task D

Goal of the navigation: Finding the yellow sphere, located somewhere in the virtual environment. By walking close to it, the navigation will finish and the task will be completed.

The task will consist of both text-based and image-based instructions. The instructions will also be available as help in the virtual environment, by pressing the «Instructions»-button in the top right corner. In order to navigate properly, you have to compare the buildings in the images with the ones in the virtual environment.

Instructions:

1. Walk straight ahead until you reach the intersection shown in the image to the right.

2. Turn 90 degrees to your right at the intersection above and keep going until you reach the intersection on the image to the right.

3. Make a 90 degrees turn to your left at the intersection above and go forward until reaching the intersection on the image to the right.

4. You should now be able to see the destination on your left. Move to the yellow sphere in order to complete your task.

All pictures obtained from Google (2020)

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