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Examining the effects of a nature experience in virtual reality

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Abstract

The report examines the effects a virtual nature experience may have on the individual. Examining the different ways nature affects the individual and then recreating a nature environment in a virtual context which allows the individual to experience the environment through using a head mounted display. Tests are conducted on users to see how their subjective feelings are changing.

Keywords: Virtual reality, nature, well-being, computer, science, computer science, thesis.

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David Granqvist, Gothenburg, 04 2022

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Introduction

Virtual reality (VR) is a simulated experience that is similar to the real world or look completely different from it. VR takes the user away from their reality into a computer processed reality through stimulating their sensations. To stimulate the user VR influence their sensations, such as the visionary-, haptic-, auditory-, chemical-, taste- or speech sensations. Different VR experiences uses different sensations, reaching the user through one stimuli or multiple . The sensations are stimulated in such a way that it corresponds to the environment the VR is creating to make the user feel like they are in that environment. The co-founder of Oculus, one of the leading companies within the VR-market, Palmer Luckey stated the goal of virtual reality as the following: "***.. to make it feel like you're actually in a place that you are not.***" [1]. The purpose of VR could then be to stimulate the users sensations in such a way that they feel totally immersed in the experience within the virtual reality. But just how far has the technology within VR reached? Is it possible for the user the obtain the same effects of a virtual reality experience as the effects of the experience outside of the virtual reality? The hope of this thesis is to come closer to an answer to this question.

The interest for virtual reality in the year of 2021 is growing rapidly. During 2021 the unit sales of virtual reality headsets are expected to reach 6.1 million units worldwide. This will lead to a total of 16.44 million units that are installed. In 2024 the expected installed base of VR headsets are set to go pass the 34 million mark[2]. This means that the upcoming three years it is expected that the amount of VR headseats will double. The market size for both consumers and enterprise of VR for 2020 reached an amount of 3.89 billion U.S. dollars and are expected to grow to a value of 12.19 billion U.S. dollars in 2024[3]. This indicates that the technology of virtual reality will keep on developing into new territories and that the consumers will have the possibility to get hold of a VR headset that possesses great quality for an affordable amount of money. Big tech companies like Meta are investing a lot in to the VR sector. This might lead to VR becoming more mainstream and the applications for VR will have the possibility to reach even more users. However so far the big investments have not payed off, but it is still to early to draw any big conclusions on the future of VR.

In today's modern societies more and more people are moving to urbanised areas, in Sweden in the year of 2018, 87 percent of the population lived in a urban

environment[4]. Urbanised areas can be more stress-full for the individual, which results in a high percentage of the inhabitants to feel stressed. as of 2018 in the United Kingdom there was reported that 74 percent felt so stressed that they had been overwhelmed or unable to cope[6]. A proven method to decrease stress levels is to be exposed to nature[5], also known as a nature pill. However, nature can be hard to reach in urban areas, especially if time is short. What if there is a possibility for a person to attach their VR-headset and take a short walk in the virtual reality nature to decrease their stress levels. This master thesis will explore and research the benefits that a nature experience within the virtual reality world will bring to the user. The research question to be answered is: **Can a virtual nature experience have a positive effect on the user?** And a secondary question that will be answered is: ***Do the quality of the graphics of the nature make any difference for the user?***

1.1 Purpose and Aim

The purpose of this project is to examine and explore the technology of today, more specific within virtual reality. To see how far virtual reality has reached in the pursuit of making the user totally immersed in the VR realm and the effects it may have on the human body. Through this research the hope is to be able to help users lower their stress levels and obtain new mental energy through a nature experience within the virtual world. The purpose is also to write a master thesis for Chalmers university of technology to obtain a graduation as an engineer.

The aim for this project is to create a virtual world where the user can experience nature and test the users mental state. This will be done through testing the mood and stress level before and after the virtual experience to see what outcome the experience had on the user. This is done to see if a virtual nature experience can have beneficial effect regarding the mood and stress levels of the individual. To obtain a virtual nature world that resembles the real nature world a design process will be conducted. The development of the virtual reality world will be conducted to test the writers knowledge within such a project.

2

Background

This project is dedicated to explore the benefits a virtual nature experience can have on the user, with the purpose to help users increase their mental-state well-being. Through the means of VR decreasing the users stress levels and refill them with new mental energy. In today's society stress is becoming a growing factor for the population of the world. No matter the economic status of the country stress keeps on growing and is a pervasive problem. Looking at countries such as South Korea, New Zealand and Switzerland they all have an average of 37 percent of the population that feels stressed, that in relation to the worlds average that is 35 percent [7]. One established method to decrease stress is to be exposed to nature [10] [9] [8]. Being exposed to nature have many benefits, one of them is increasing the individuals mental-state well-being [11] [12] [13] [14]. Can these positive effects of being exposed to nature, a nature experience, be of the same characteristic for a virtual nature experience?

To create a VR experience a simulation game type approach will be taken, where a virtual nature environment will be created. In the virtual environment the user then, through a Oculus Quest 2, can roam freely through a first person view exploring the virtual world. To achieve a nature experience a nature environment need to be defined, since this is a subjective term. One person might think of the nature in one sense and another person in a totally different sense. This is due to personal and cultural influences. If a person is asked to describe "wilderness" the average person will say that it is an area that lack the influence of humans [19]. For this project a nature environment will be defined as an area that holds living organisms, such as plants and animals and that it is separated from too much human influences. Nature environment such as Slottskogen and Ramberget in Gothenburg is considered to be located to close to urban influences and will not be used as inspiration. Rather the nature environment has to be separated from to much influences from urban entities. Botaniska in Gothenburg is an area that could be used. In the VR there will be virtual objects that resembles forest objects including living organisms, such as plants.

2.1 Nature's effects on humans

Throughout history humans have had a close relationship with nature, experiencing it from the very first moment of the morning to the vary last of the night. During the long evolution of humans nature has always been next to their side. This, Wilson and Kellert, claims lead to humans developing a natural love for nature, an affection that all humans across the world feels[18]. This is because it is integrated in our genetic code that was created through evolution. Humans started their separation from nature when civilization began to emerge, as communities started to grow bigger and cities expanded their boundaries which lead to nature being replaced by human facilities. With the catalysts of the industrial age and now the information age the average human has never been so separated from nature as she is today. Today the life of an average resident might look something like this: Waking up in an apartment surrounded by other apartments, walking to their shuttle station in the concrete jungle to commute to their office. In their office they interact with a screen throughout the day and when they are done with their job they return back to their home. This lifestyle have a lack of interaction with nature, and what this does to the body and mind is a hard thing to research, since there are so many factors that come in to play in a human life regarding to their well-being, but the term Nature-Deficit Disorder has been coined by Richard Louv. He argues that separation from nature will have profound implications on humans, for the present generation and for the coming ones[15]. As professor J. Arthru Thomson stated 1914 [35]:

"What then do I mean tonight by the healing power of nature? I mean to refer to the way in which Nature ministers to our minds, all more or less diseased by the rush and racket of civilization, and helps to steady and enrich our lives. My first point is that there are deeply-rooted, old established, far-reaching relations between Man and Nature which we cannot ignore without loss... there would be less "psychopathology of everyday life" if we kept up our acquaintance... we have put ourselves beyond a very potent vis medicatrix if we cease to be able to wonder at the at the grandeur of the star-strewn sky, the mystery of the mountains, the sea eternally new, the way of the eagle in the air, the meanest flower that blows, the look in a dog's eye."

What has been researched and proven in contrast to what the lack of nature does to the human is that exposure to nature will cause a improved mental-state of well-being [13].

This topic, what benefits does it have to be in nature, is an easier question to conduct research within, since it is enough to spend a certain amount of time in nature and then compare the effects of it. It is possible to measure data such as subjective well-being, cholesterol-values, skin-conduction etc. During the last two decades there has been conducted a lot of research in this area. And the result has been that there is a positive effect for humans to spend time in nature. Thanks to the research done in this area it is now widely recognized that nature can be of help to cure human imbalances and in the medical sector, nurses are now encouraged to prescribe and encourage time in nature [16] [17].

2.1.1 How do nature affect the body?

Within the present research conducted on how nature affect humans it can be categorized into four different pathways. The first pathway is air quality. Through the vegetation, such as shrugs and trees, the nature affect the content of the air. The vegetation filtrates the air out of gases and particulate matter [20] which makes the air of higher quality to humans. But it can also have negative effects to the air quality, such as releasing pollen, which may cause allergic reactions for some individuals. The second pathway is physical activity. Physical activity has been shown that it increases mental and physical health throughout a humans life [21]. Often when a individual is going to visit a nature environment they have to make some kind of physical effort, such as walking, biking etc. to get to the nature environment. As well as when the individual has reached the nature environment it often includes some kind of physical activity, such as walking in the woods. This will then cause a positive effect on their health since they are moving their bodies performing physical activity. The third pathway is the social aspect. When going out to a nature environment there is a higher chance that the individual will run into another person and create a social interaction. They will also have a higher chance of meeting their neighbours and developing a better relation with them. Research has shown positive effects on human well-being through social interactions [22] which will have a higher chance to happen if the individual leaves their home to visit a nature environment.

The final pathway, and the pathway that this thesis will have a focus on, is stress reduction. Within the subject of stress reduction in correlation to nature there are two major explanatory theories, the stress recovery theory and the attention restoration theory. They both addresses a subconscious process that is activated due to an evolutionary aspects. Stress reduction theory (SRT) claims that when humans see a profitable view, profitable in terms of surviving, such as water and vegetation, they connect that with a good chance of survival as they have access to water, hopefully food and having a good chance of spotting incoming dangers, predators etc. [23]. This will then cause a release of tension and negative thoughts will decrease [24], which will cause the individual to feel better.

The other theory, attention restoration theory (ART), says that spending time with nature allows the mind to regain its ability to focus [25]. It relays on the work of William James that claimed that attention can be divided into two different kinds, one that is voluntary and the other that is involuntary. This means that humans have a direct attention that can be focus with the power of the mind and then the other, indirect attention. Indirect attention just happens without having to think about it [26]. For example when driving a car or transporting with the bus the individual can suddenly "wake up" and have travelled a recognisable distance without actually noticing it, this is indirect attention. When viewing nature the indirect or involuntary attention takes over allowing the voluntary attention to rest and be restored, which will leave the individual with a new amount of voluntary attention. There is a overlap between the theories, SRT and ART, as both relays on the subconscious mind that causes an effect in the body to calm down. Another interesting viewpoint is that one of the theories may cause the other to appear. As

in SRT the relaxing effect of viewing a survival-friendly view may cause a restoration in the voluntary attention as the individual is more relaxed. Same goes for ART, the regenerated voluntary attention may cause the individual to feel more calm and be relieved of stress.

2.1.2 Photos and sounds

There has been research showing that the individual does not have to be in the nature environment to experience its healing benefits. A study was made were participants was shown images of a vegetation-rich area in contrast to the control group that was shown urban environment[27] [28]. Tests were conducted after their stress level were artificially increased, such as after an examination or after watching an video that causes an increase in stress levels. The participants that was shown the nature environment photos showed a subjective decrease in arousal and fear and a quick improvement in their mental well-being compared to the participants that did not view the nature environment. Tests has also been conducted with objective data, such as measuring alpha wave activity through an EEG, muscle tension through a EMG and the autonomic nervous system arousal through skin conductance. These test also showed a positive influences of all the previous mentioned measurements when viewing a nature scene [29] [30].

Sound is another factor that can affect the well-being of the human. Although there has been a lot of research regarding natures ability to nourish the human body, the effects of the sounds that nature produces has not been as well research. There has been one study that examine the calming effects of nature sounds on the human body after a mental stressful task compared to sound from a noisy environment. The research showed that after psychological stress, psychological recovery is faster with calming nature sounds in comparison to noisy sounds [31]. However the nature sound was not compared to the effects without a noisy sound.

2.1.3 Contribution of contact parameters

What is the optimal way for a nature experience to help the human to recovery and to a state of better well-being? Parameters such as frequency, nature quality and duration are of importance here. But it is hard to define what is the optimal dose of a nature experience, especially since most of the studies have their own definition of nature, where urban environment and nature environment is mixed in different degrees. Frumklin et al. [32] shows the difficulties in quantifying a nature experience dose. And right now the guidelines for a nature experience are few. Shanahan et al. [33] came up with the result that individuals who visit the nature for a longer duration had lower rates of depression and lower levels of high blood pressure. Individuals who visited the nature more frequently but with shorter duration showed a greater social cohesion. A major factor in the article were the physical activity that showed co relation to both the frequency and duration. Hunter et al. [34] shows in their research that the optimal duration is 20 to 30 minutes of nature exposure. During that time the drop in the cortisol level of the individuals are at its highest drop. Benefits keeps emerging after that time but at a reduced rate.

There is still no defined optimal dose of a nature experience, due to the difficulties in quantifying a nature dose, and more research needs to be done in this area.

It has to be said that all humans do not see the nature as a relaxing place. Phobias such as xylophobia, the fear of wooded areas, or zoophobia, the fear of animals may cause the experience of nature to be stress full and unpleasant.

2.2 Virtual Reality

Virtual reality (VR) is a computer generated environment that brings the user away from the real world into the VR world through different means, such as head mounted display, bodytracking, 3D graphics etc,. As mentioned earlier the goal for VR is to make the user feel like they are in an environment that they actually are not. For this goal to be reached there are three characteristics[1] that have to be applied on the user. The first of the three characteristics is immersion, that the user feels immersed in a computer generated scene. Immersion describes to what extent the virtual reality is capable to create a illusion of reality for the users sensations. The second is interaction, the content in the virtual world can be interacted with. The third is independence, the user have an independent view of the world and can react in an independent way to the environment. These three characteristics will create an immersive experience for the user which will create a feeling of presence in the virtual world.

2.2.1 Presence

Presence, unlike immersion, is a conscious state. It is the psychological sense that the user is located in the virtual environment. Presence is a subjective feeling of the individual, a feeling that describes to what extent they fell like they are in an environment they physically are not. So with a high level of immersion combined with interaction and independence will create a strong feeling of presence, which can be argued is the goal of VR[1].

To create a feeling of presence in the virtual environment the users sensations has to be manipulated. This is done through shielding of the sensations from the real world and changing it to sensations from a virtual world. With a VR-device that blocks input from the real world and sends output to the user to create a virtual world, and then takes input from the user to manipulate the virtual environment based on the users action, takes the user to a VR world. See figure 2.1. For example if we look at a visual simulation, we first have a computer that generates 3D graphics. These graphics is then shown through a head mounted display. The eyes take in the information that is shown in the head mounted display and send it to the brain, which causes a feel of presence.

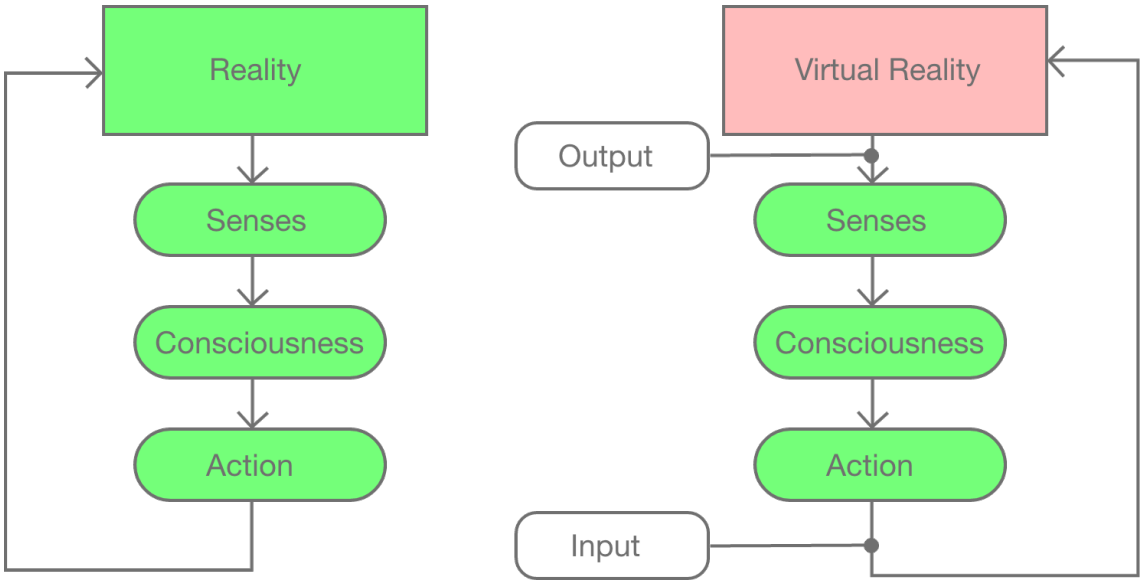


Figure 2.1: VR flow diagram [1]

2.2.2 Immersion

All the three different categories earlier mentioned, immersion, interaction, Independence, create a feeling of presence through their own key technologies with the goal to induce the highest possible feeling of presence. The key technology to create an immersive experience is the display. The main focus is the visual display, but there are also other kinds of displays, such as auditory, tactile senses etc. The most popular visual display is the head mounted display (HMD). But there are others, for example large projections or screens, such as walking in to a room that has screens covering the walls. Here we will focus on the HMD. There are a wide variety of HMD on the market, with ranging price classes and quality to them. The key properties of a HMD is their lens, display and ergonomic. Looking at figure 2.2 we can see what a HMD consists of, in this specifically case the build of an Oculus Rift. Closest to the users face is a foam, to make the HMD ergonomic and good to wear. Then comes the lenses, which typically can be regulated to match the user. Then there is a regulator for the position of the display. A high definition screen with a circuit board behind it. And finally there is a cover to keep the parts together and protect them from damage.

One of the goals of a VR-display is to create depth. To do that the HMD has to create an illusion that the object is further away than the actual display. As we can see in figure 2.2 the display is closer than the vergence distance, the percieved distance. The user's eye look at the display of the HMD which creates an illusion that the object is further away than the actual display. In figure 2.3 we can see the relations between the display distance and image distance to the lens and the focal length of the lens. Here we can see why it is important to be able to regulate the lenses for the users individual need. This so the virtual image stays in focus as all humans have different faces and length between the eyes.

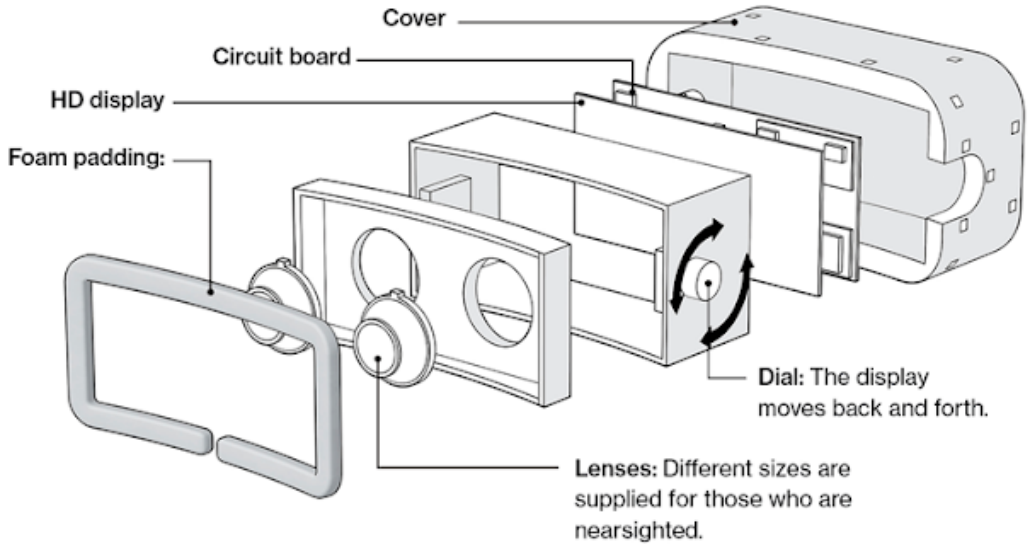


Figure 2.2: Composition of VR head mount display [36]

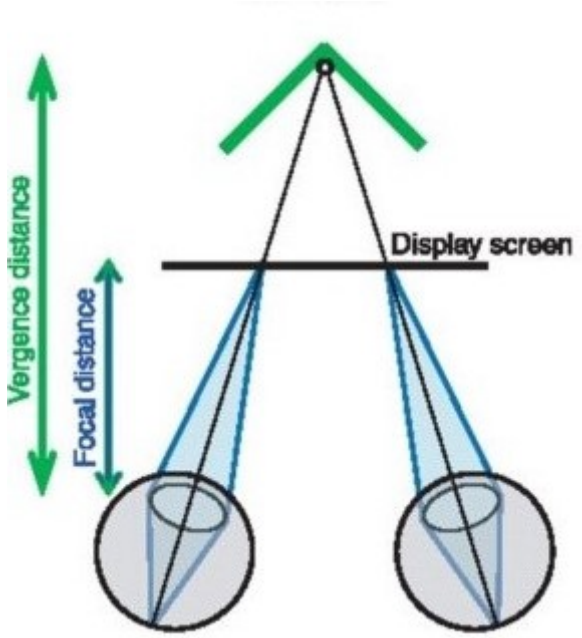


Figure 2.3: Focal and vergence distance [37]

The field of view of a human is slightly more than 210 degrees [39] and most of the VR HMD available on the market has a field of view around 100 degrees. The problem is if the field of view of the HMD should be increased the amount of pixels per degree will be lowered, causing a lower quality in the graphics. The resolution for the latest HMD are right now around 2000x2000 pixels, which is about 20 pixels per degree. However the human eye can not see in high resolution for a field of view of 210 degrees. Rather it is a closer to a degree of 30 where the eye is focusing and the area around it. Therefor some companies are using foveated rendering, the name

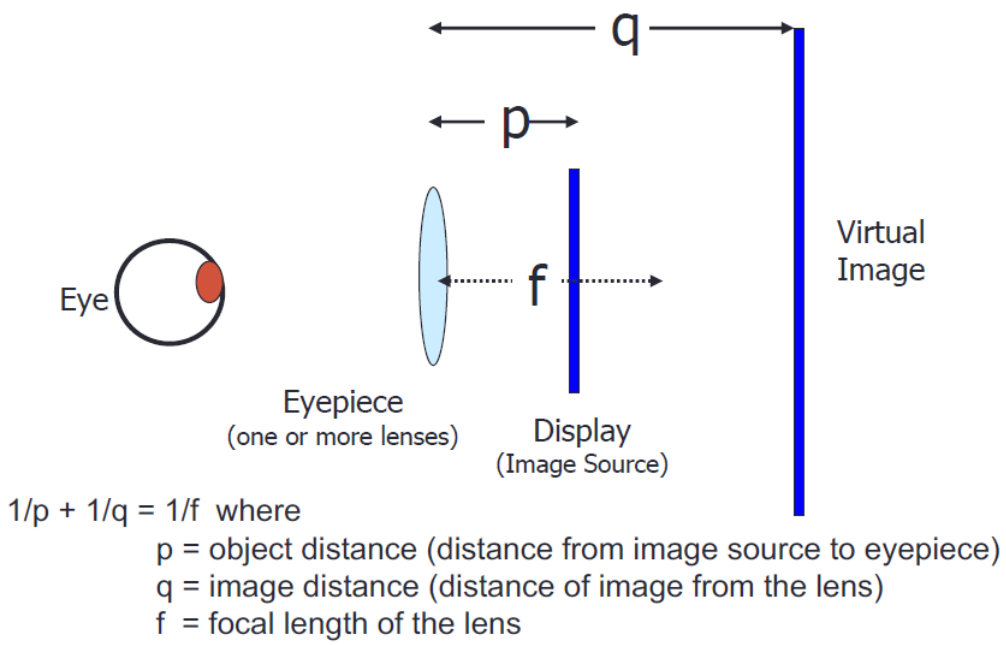


Figure 2.4: Simple magnifier HMD design [1]

comes from the fovea, which is the central part of the macula and has the highest concentration of cone photo-receptors. This means that the HMD tracks the eyes to see where they are looking and focusing the rendering to that part of the display. This allows the HMD to reduce the quality in the peripheral view and have higher quality in the center view. This is a trade-off that comes when designing a HMD, with a greater field of view comes a lower resolution.

2.2.2.1 Audio and haptic displays

Even if the visual aspect is the main focus in the virtual reality, audio definitely has its place in VR. It can enhance the feeling of presence for the user, for example in a horror game the sound can make a huge difference. It can also provide feedback to the user, for example in an airplane simulator it can alert the user if something is wrong. Audio can be retrieved through two different means, either sampling it from nature or creating it synthetically through computers. Sampling the audio is done through a recording device. One microphone records a monophonic sound which does not allow for positioning. With two microphones placed apart stereo sound is acquired, which allows for perceived sound positioning. Placing microphones within the ears of a dummy-head allows for binaural sound. Binaural sound is intended to create a 3-D sensation for the listener to make them feel like they actually are in the place it was recorded. Sampled sounds provides a easy way to create realism but is difficult to manipulate, it is the opposite of synthesized sounds. Synthesized sounds are created through the use of simple waveforms such as sine- or sawtooth-waveforms. Different waveforms can be manipulated through their frequency and amplitude and then be combined in various ways to create a synthetic sound. The synthesized sounds are expensive to compute before playing but they provide an

easy way to be manipulated. With synthetic sound it is also difficult to provide realism.

Another display that can improve the immersion for the user is haptic displays. Haptic displays greatly improves the realism for the user. Especially the hands are of high importance since they have a high density of touch receptors. There are two different types of haptic feedback. First tactile, which uses the receptors underneath the skin to receive feedback about the temperature, vibration, texture etc. The second type of feedback is kinesthetic. This feedback uses the tension in the muscles, joints and tendons to interpret the information provided. For example if one holds a football, the brain analyzes the angle of the joints, the pressure the hands have on the ball and the amount of force the muscles need to deliver. This will create a understanding in the mind of the size of the ball and weight of the ball. Tactile is the feedback of touch and kinesthetic is the feedback of force. One type of tactile display is a bodysuit that send out tactile feedback through vibrations to the user. A kinesthetic display can be a glove that contains resistance, when the user is trying to close their hand the glove provides resistance which will create a kinesthetic feedback.

2.2.3 Independence

The key technology to create independence for the user is tracking, such as changing view point and allowing independent movement. When the user changes position in reality their position in the virtual world must also change. For example, if the user turns their head, the graphics in the VR must change with the rotation of the head or if the user reach out to grab something in the virtual world, then that virtual object should be grabbed. This requires tracking to constantly update the system with information about the movements and position of the user relative to the real and virtual world. This is done through either 3-degrees of freedom (3-DoF) or 6-degrees of freedom (6-DoF). Degrees of freedom (DoF) explains in how many ways a rigid body can move in the three dimensional space. In three dimensional space there are six DoF that the body can move within. There are three different directions that the body can rotate towards, that is the x-, y- and z-axes, also known as pitch, yaw and roll. Then there are three different directions the body can move in, transitional movement, which is moving in the x-, y- and z-axes. This can also be seen as moving up and down, left and right and backwards and forward. With 3-DoF the system can only track the rotation and with 6-DoF the system can track both the rotation and the transitional movement, see figure 2.4.

To allow for six or three degrees of freedom tracking devices must be used. There are two different kinds of tracking technologies. One being an active tracker, that is that the device is sending out a signal, such as an GPS. The other is a passive tracker, it senses the world, such as a compass or accelerometer. These two types, active and passive, can also be combined in to a hybrid tracker. The trackers have the same performance criteria to make sure they provide the correct data. Static and dynamic accuracy is on of the criterias, meaning the ability of the tracker to determine the position in space, both when moving and standing still. Then there is

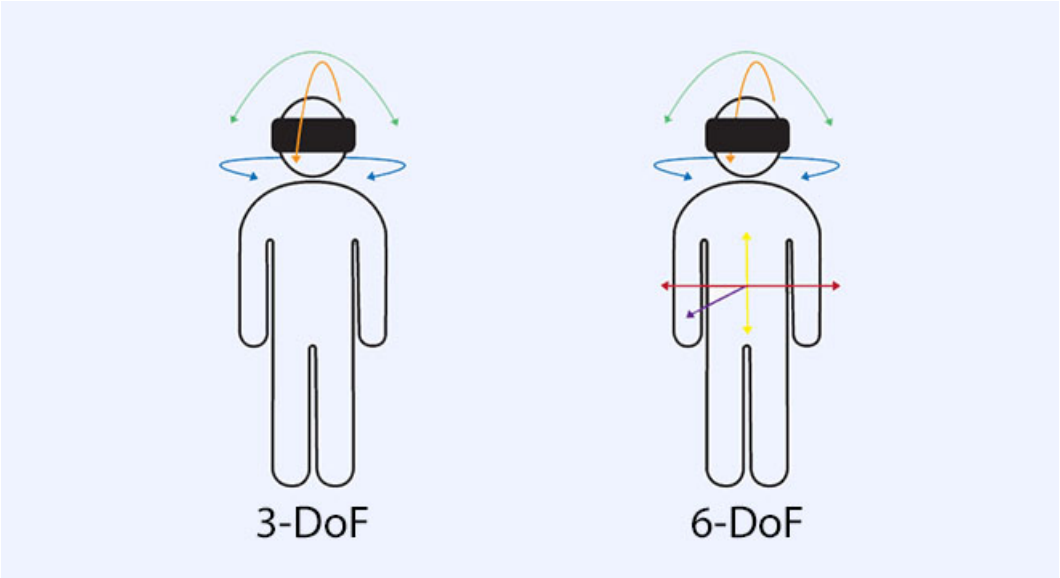


Figure 2.5: 3 vs 6 degrees of freedome(DOF) [38]

latency and update rate, how long time it takes for the tracker to detect the change in position that has been made and how often it updates the position. The three final are jitter, signal to noise ratio and drift.

Two popular ways to keep track of the user is to use outside-in tracking or inside-out tracking. Both of them using a passive device in terms of optical tracker. Outside-in uses a fixed optical tracker, usually placed around the room where the HMD is used, and then have landmarks on the HMD that it can track. Inside-out tracking have their optical sensors on the HMD and uses fixed landmarks in the room to track the movement. For example there is the Oculus Quest that uses inside-out tracking. It has four cameras in the corner of the HMD that helps it to create a map of the room, several landmarks, and then tracks the movement related to these landmarks. The HTC Vive on the other hand uses outside-in tracking. It places two base stations in the room that is used to track the movement of the HMD and the controllers.

Head mounted displays have one attribute that can liberate or diminish the independence of the user and that is if the HMD is tethered or untethered. Meaning that if it is tethered the HMD has to be connected to a computer to be able to work. This might cause the independence to become lower but there is benefits to it as well. With a tethered HMD it is possible to use the computational power of a computer that can be more powerful than a stand-alone HMD. This can result in better graphics, higher update rates etc. which causes the user experience to be more satisfactory. This requires a computer with high performance, which is not always the case. If a computer with poor computational power is connected then it will create low resolution images and low update rates, leading to a non-satisfactory experience for the user. With the tethered an analog cable has to be connected to a computer. This limits the independence since the user has to relate to the cable. Turning more than 360 degrees could become a problem, since the user might get wrapped in the cable. As well if the cable is not long enough, the user will be limited

in its transitional movement. This could be solved by having a cable that is long enough and attaching it to the ceiling through objects that let the cable run freely. Untethered devices on the other hand provides a higher degree of independence, since there is no cable that restricts the user. But it might fall short in terms of performance compared to an thetered HMD. It can not provide the computational power of a computer and it is running on a battery that will run out.

2.2.4 Interaction

The key technology for interaction is the input devices. Input devices are physical devices that support the user in their interaction with the virtual world through mediating user input. This can be done through various ways. For example the users body movement can be mediated through position trackers, data gloves, exo skeletons etc. and the users voice could be mediated through a microphone. The goal of the input devices is to convey information to the virtual environment. For the usual computer a mouse and keyboard is used as input devices. This works great for the desktop user interface but it might not be the best for a VR environment. Therefor we will take a look on the different input devices seeing their pros and cons. Firstly we will look at hand input devices and then no-hand input devices.

2.2.4.1 Hand input devices

Hand input devices are devices that are used by the hands to convey information to the VR. There are several different ways to convey the information from the hands in to the VR. One type of input device for the hands are world grounded devices. These are devices that are stationary or constrained in the real world. These types of input devices are not ideal for the VR experience since it restricts the independence of the user. However it can be good to create a higher degree of presence for a flight simulator game, where the joystick that controls the plane is fixed in a certain position. Another type of input device for the hands are non-tracked handheld controllers, for example a playstation controller. These are good for navigation with buttons and joysticks and provides good independence since they are wireless and can be moved around. The tracked handheld controllers are superior to the non tracked handheld controllers because they provide the user with both the buttons and joysticks, plus that they provide the system with tracking. Tracked handheld controllers are considered one of the best options for VR and is seen as a enhancer for the VR experience. Tracked handheld controllers provides haptic information to the user through vibrations and with a separate left and right hand controller the users hand movements can be mapped to the VR. Then there are hand worn devices. These are devices worn on the hands and/or arms, such as gloves or an armband. These creates a high degree of independence since the hands and fingers are free and can be held in comfortable positions and interact fully with real objects. Hand worn devices can also provide a high quality tracking of the hand gestures providing a higher degree of immersion. The last hand input device are hand tracking through sensors, such as a camera. This provides natural feel for the user but it comes with some flaws as well. The user has to hold their hands in front of the sensors, which may cause a lower degree of independence and fatigue in the muscles. There is also

no haptic feedback in terms of vibrations for the tracking through sensors.

2.2.4.2 Non-hand input devices

Non-hand input devices convey information to the system from other parts of the body than the hands. One of the body parts that is used as input is the head. To track the head movement there is optical tracking through image sensors, using inside-out or outside-in tracking to convey the information about the head position. There is also non-optical tracking for the heads position, such as gyroscopes, magnetometers, and accelerometers. Eye tracking is another device that can be used as input. Eye-tracking uses infra red light to illuminate the eye and then catch the reflections caused by the infra red light to see where the eye is looking. This provides the user with hands-free input and it can be used to understand where the user is putting their attention, which can be good for foveated rendering. Facial tracking is possible through image sensors. Mounting a camera on the HMD to read the mouth and the mediate that information to the system. Other than the head the full body can also be used as a input source. Full body tracking uses suits or cameras that register the movement of the body. This can cause a high level of presence when all the movements of the user can be conveyed in to the system without having to perform an extra action. Then there is pedestrian devices. Pedestrian devices capture the translationall movement, such as walking or running. This can be done by using a treadmill.

3

Theory

In the following chapter we will take a look at the theories about designing a good user experience in VR. We will also look at the game design concept of MDA.

3.1 Designing pleasurable experience

To create a pleasurable experience for the user one has to take many factors in to account. This virtual environment that will be created in this project will try to be as user friendly as possible and for that to be achieved different design methods will be taken into consideration. Firstly, the VR world that the user will step into will allow interactions with virtual objects. The user will be able to move around in the environment, changing their position relative to the objects in the VR. As it is an interactive product, interaction design becomes highly relevant. The goal is to design a product that is enjoyable to use, the usability is of high priority. In human-computer interaction Preece et al. state that interaction design is *designing interactive products to support people in their everyday and working lives* [40]. To do this according to Preece et al. it is important to understand interaction, the user, how interfaces affect users and the process of interaction design.

Understanding interaction between the user and the application is important for the development or redesign of a product. If one is faced with a design problem that needs to be fixed it can be hard to know where to start. The decisions made in the beginning of a design process can have a massive influence over the whole process. For example if one dives straight into coding without understanding the interaction, leading to an investment of effort, time and money into an idea that in a later stage has to be dismissed. Therefore it is important to have a clear understanding of the what, why and how relative to the design. To do this we have to understand the problem space through clarifying the usability and user experience goals as well as conceptualize what we want to create and articulating why we want to do so [41]. When this is done we have to understand the user, especially their cognitive aspects[42]. What kind of mental models do they posses and how can we use it in the design to create a user friendly experience?

When the user is interacting with an interface it can cause different emotional responses within the user. This is what is called affective aspects of interaction design. What is strived after here is a positive affect from the interaction, such as

the user feeling at ease, comfort and happiness [43]. This can be achieved through well-designed interfaces, such as a aesthetically pleasing interface or a expressive interface. On the other hand a bad-designed interface might elicit a negative response, such as sadness and frustration. To increase the chances of creating a design that have a positive effect on the user a predetermined design process is executed. A design process can take many forms and it can consist of one or several steps within it. Such as Jones three step process that consists of divergence, transformation and convergence [44]. Preece et al. mentions three key aspects to a design process. That is the need to focus on the user, specify the usability and user experience goals and finally iterate [45] [46]. Focusing on the user allows for feedback about the design that can help to achieve a good design. Setting clear goals will allow the designer to choose between different design choices with more ease, as well as checking the development of the product when it is already stated what it aims to achieve. Iteration means that the process starts over, bringing along the results and knowledge from the last iteration. This allows the design to be changed based on feedback received either from user tests or from the designer themselves. This is crucial because designers never get the perfect design the first time, a good design is in need of iteration [46].

3.1.1 Understanding the problem

The first step in a design process should be to understand the problem that is trying to be solved. That is done through understanding as much as possible about the user and identifying their needs, and based on the users needs establish requirements that help the design process[47]. This is done through three steps, starting with gathering data, then analyze the data and finally establish requirements(a statement about a intended product that tells what it should do or how it should perform) based on the data. This is an iterative process, but even if the principle is to execute these steps in order from one to three ,one might have to jump between them. For example after gathering the data and starting to analyze it, one might realize that more information is needed leading to redoing step one to gather the necessary data.

To gather the data there are different techniques to use. Such different techniques are questionnaire, interviews, focus groups and workshops, studying documentation and naturalistic observation. They all have their own advantages and disadvantages, but regarding to this project a naturalistic observation seems to be one of the top choices. Naturalistic observation means spending time with a potential user, observing them as they go about. This is done because it can be hard for humans to articulate how and why they behave in a certain way. By observing them in their natural context a better understanding of the activity may arise. However this technique may be time consuming and produce a lot of data. After acquiring the data it has to be analyzed. This can be done through a thematic analyze. The following list explains the steps in a thematic analyze.

1 **Familiarize with data:** Read through the data carefully and thoroughly with the goal to find similarities and patterns.

2 Create initial codes: Create codes from the similarities and patterns discovered in the previous step

3 Search for themes: With the codes created it is possible to get an overview of the data that can then be grouped in to themes.

4 Group codes into themes Put the codes into the themes.

5 Review and revise themes Make sure that the codes in the themes actually belong there.

6 Write result When the themes have been reviewed and revised a result can be presented.

The importance of establishing requirements was shown in an article from 2000 that looked into what causes a IT project to sink or swim. The most common problem when a project failed was because of unclear objectives and requirements definitions[48]. To avoid this different kind of requirements will be established, see the following list.

1 Functional: Capturing what the product should do

2 Data: Capture the type, volatility, size/amount, persistence, accuracy, and value of the amounts of the required data

3 Environment: Physical environment, such as wind, water dust etc. Social environment, will it be for collaboration etc., technical environment, what technologies will the product run on.

4 User Capture the characteristics of the intended user group.

5 Review and revise themes Make sure that the codes in the themes actually belong there.

6 Usability Capture the usability goals and associated measures for a particular product.

3.1.2 Creating a solution and testing it

When an satisfying understanding of the problem has occurred and a set of requirements has been decided upon, it is time to try and create a solution to the problem. The first steps to take is to create a conceptual design explaining what the product will do and how it will behave. From the conceptual design prototypes can be created. Prototypes is a approach to open up for discussion about the idea with stakeholders, they are a a tool for communicating ideas between group members. Building a prototype is also a good approach to test the idea for the designer by their own since building prototypes encourage reflection of the design [49]. Prototypes can answer question and provide the designer with more information before a choosing between two alternative designs. For example they can be used to test which color to choose or to find out if the user interact with it as they are indented

to interact with the design. Depending on what the prototype seeks to answer, it has to be designed in that way. Some prototypes can be of a low-fidelity type and still answer the asked question, while other prototypes have to be of a high-fidelity type.

Low-fidelity prototypes are cheap to create, in regards of time, money and effort. They are ideal for an early stage when the final product is still vague. Low-fidelity prototypes main goal is to explore. For example two types of low-fidelity prototypes are sketching and storyboarding. Sketching can be done with paper and pen or through a software. The intention is to create something simple to get an idea into the world so it is easier to grasp it. It can be no more than stick figures or lines. Storyboarding consists of a series of coherent sketches showing how a user might interact with the design that is being developed. A high-fidelity prototype is a prototype that is getting closer to the final design. It should resemble how the final design is intended to look, both in material and feel. High-fidelity prototypes are more expansive to create compared to low-fidelity prototypes which can lead to more accurate answers regarding the design, but it might cost more than the outcome of it.

To make sure that the design that has been created is usable and does what it is expected to do user evaluations comes into play. Many times designers skip this step as it is demanding regarding time and money costs. Rather they test the design by themselves or ask colleagues to test it, which might give a false perception that the design works for all users, but in reality the intended users will not now how to interact with the design in its intended way. It is therefore important to involve users in evaluations to get the correct picture of how the design works and also result in a good understanding between the designer and the user. Depending on what the evaluation seeks to answer the evaluation might vary. For example if a company creating sledges for kids want to know if the sledges are of a good design, they will go to the kids and ask what they think about the sledges. Or if another company designs phones for elder people they will go to elder people and see how they interact with the design. There are different ways of conducting a evaluation such as usability testing and fields studies. In usability testing the evaluator is in control and asks the user to perform certain tasks related to the design, prototype or product. The test is often carried out in a laboratory and controlled environment. A usability test can then be combined with a questionnaire or interview to produce more data.

3.2 Designing VR

Our current understanding of user experiences and designing them have developed out of 2D-screens. With VR there are new additional factors that come in to play compared to a 2D-screen. Now the user can be fully immersed in an environment having the possibility of 360 degree view, perceive their physical location, have their movement tracked and perceive depth. The established guidelines and patterns available for user experience design do not take this extra factors in calculation.

This can cause problems for the designer when trying to apply the 2D guidelines for a 3D environment. To design for a 3D-environment new guidelines and patterns has to be established. Right now the VR-sector is still in a young phase but thanks to different communitites within the VR sector, such as blogs, device companies, academic research, guidelines and patterns have started to emerge. Vi et al. have used A total of 60 web resources, 1 peer reviewed paper, 1 book, 3 non-peer review academic sources, and 3 traditional user experience sources [50] to derive eleven guidelines for designing HMD user experiences for extended reality (XR). XR also includes augmented reality(AR) and mixed reality (MR), even if most of the resources Vi et al. found were based upon VR.

3.2.1 Guidelines for HMD virtual reality applications

The eleven guidelines brought by Vi et al. will be presented and explained.

1. Organize the Spatial Environment to Maximize Efficiency

Definition: "XR is inherently spatial. Use space as an organizational tool to create an environment that is comfortable to use and minimizes the amount of conscious thinking a user has to do to accomplish his or her goals" [50].

VR can utilize how humans interpret spatial environment to create a dynamic environment and free working memory for the device. For example taking use of the FOV earlier discussed. The designer still has to have in mind the physical aspects of the human body. There might not be possible for an user to reach a object two meters up in the air but for another user it will be possible. It is therefore important to take the physical aspects of the human body in consideration and place objects in the virtual world where the user can view it and interact with it in a comfortable manner for a longer period of time. At the same time its important to use the whole spectrum of the spatial environment. Information and objects should be placed in such a way that the user will not perceive them to be cluttered. Objects and information of similar type can be grouped together to use the attention chaining behaviour to let the user find what they are looking for more easily and efficiently. The environment need to be designed with a focus to use the entire space but at the same time limiting the physical movement required by the user to achieve their goals.

2. Create Flexible Interactions and Environments

Definition: "Provide users with the capability to customize the application to their personal preferences and comforts. Build in options that cater to a range of users that take into account different experience levels and physical considerations" [50].

It is important to design the application so its enjoyable to a wide range of users. Therefor it helps to let the users customize their own interaction with the application to fit their needs. This will help with their overall experience towards VR allowing for more ease of use and satisfaction. The different levels of knowledge towards VR needs to be taken in consideration, providing cues for novice users and provide

the possibility to speed things up for the intermediate and expert users. Letting the users decide and define what their own level of comfort is through allowing customization, such as personal boundaries.

3. Prioritize User's Comfort

Definition: "The XR application should keep the user safe by taking extra precautions to maintain the physical, physiological, and environmental comforts for the user throughout the experience." [50].

Being in a VR environment exposes the user to a 360 degree experience that includes many different factors that can affect the users comfort. It is therefore important to avoid letting the user be situated in a situation that causes discomfort and distress. The personal space of a user is of utmost importance. Placing object to close to the head can cause both mental and physical discomfort. Objects should be placed in a proper distance and not to close to the user. The user should be in control of their personal space and be able to regulate what objects enter their personal space.

Physical discomfort might arise when a user are immersed in a virtual environment and expects to feel on thing but is feeling another. Such thing like motion sickness might occur for the user. The designer needs to have this in consideration and design with the goal to prevent physical comfort. The designer also needs to design with the intention to prevent environmental discomfort, such as small spaces might cause claustrophobia or heights might cause acrophobia with the user.

When interacting with 3D environments physical fatigue might occur. The designer needs to be mindful about physical draining situations. An VR experience can provide repetitive and prolonged physical activity that might cause fatigue with the user. Such as not letting the user stare at a object for a long period of time that causes stress on their neck.

4. Keep It Simple: Do Not Overwhelm the User

Definition: "The more there is, the less the user remembers. Create simple and relevant elements in an environment that do not distract the user from what is important." [50].

Virtual environments provide the user and designer with a big share of virtual space that can be utilized. But too much information in this space might cause an overload for the user. Finding the sweet spot for the right amount of information can be tricky, the designer should therefor always aim to have a minimalistic approach to the information provided for the user. As all the information competes over the users attention its important to keep irrelevant information away from the user. Tools and information should still be available for the user but not in a distracting way. It can be hidden for immediate interaction through minimizing it, turning it off etc. and only shown when the user wants it.

5. Design Around Hardware Capabilities and Limitations

Definition: "The way users interact and explore the environment will be greatly dependent on the system they are using. Always keep the capabilities of the hardware in mind when crafting XR experiences" [50].

Take the hardware into consideration and design out of its capabilities, such as input type, tracking limitations, computation power etc. The designer needs to be comfortable with the hardware and know its capacities and limitations to be able to use the full strength of the medium.

6. Use Cues to Help Users Throughout Their Experience

Definition: "Create signifying cues to help users to get started, provide additional information, guide user's attention, and simplify choice within the application" [50].

With a new medium like VR it is easy for the user to get lost or receive to much information during their experience. It is therefore necessary for the designer to provide guidance throughout the experience with the goal to prevent frustration for the user. This can be done by providing cues, such as directing the users attention on where to go, what to do and what not to do. Still it is important to not overwhelm the user with information, rather the information that needs to reach through to the user has to be conveyed in an comfortable and efficient manner.

7. Create a Compelling XR Experience

Definition: "XR allows users to be immersed in the virtual environment. Enhance their senses through visuals, audio, and narrative elements that captivate them in the experience." [50].

Being immersed in a VR exposes the users senses more than a 2D experience. This provides extra challenges for the designer as well as opportunities to design for an even more immersive experience. To make it a enjoyable experience there should be visual elements that are enjoyable to interact with and view. Audio should be used in such a way that it enhances the experience. For example the use of spatial sound makes the user feel where the sound is coming from, it is a good way to enhance the experience.

8. Build upon Real World Knowledge

Definition: "Help users to understand how to use the application by designing the interactions, objects, and environments around existing knowledge of the real world." [50].

The mental models of the users should be capitalized on, taking advantage of the knowledge they already posses. This can be done through designing upon real world knowledge. Using the real world as inspiration and creating an virtual environment out from it can help the user to understand the design without extra guidance. It is important to map actions to outcome of an object that match the users mental model. The visual characteristics of an object may intend it to have certain abilities, make sure that the virtual object will behave in such a way that is presented with

its visual characteristics. If the virtual object do not behave in such a way that might be expected it is important to inform the user of its limitations and build boundaries that hinder it from being performed.

9. Provide Feedback and Consistency

Definition: "Use feedback to generalize perception of events and interactions. Additionally, feedback should be consistent such that users can build an understanding of what they can and cannot do within the application." [50].

Allowing the user to make informed decisions based on a consistency in the feedback will allow for a better user experience. In the digital world objects may not behave in such a way that is expected. In the real world we assume how objects behave out from their features, such as if a object is heavy, tall and soft. In the virtual world however the objects feature may not be mapped to the way it behaves. It is therefore important to consistently inform the user how to interact with the application. This can be done through informing the user about actions, if they are possible to perform, if they have been executed, if it was possible to execute an action but it was performed in the wrong way etc. The users should have the possibility to explore the application and learn how to use it out of their own experiences. They should be provided with enough feedback that they can explore the application on their own.

10. Allow Users to Feel in Control of the Experience

Definition: "The application should act and respond in a way that gives users the sense that they are in charge."[50].

User can feel vulnerable when they are immersed in a virtual environment. It is therefore important for the designer to make the application convey to the user that they are safe and in control of their own experience. This is done through not forcing any action upon the user. The user should be in control and the application should not try to interpret what the user wants to do and execute it. There should be an easily accessed way of exiting the current state for the user. This should be able to be executed with minimal resistance from the application.

The application should be honest towards the user. This is done by having the application act in such a way that the user expect it to act. The application should always let the user decide their movements. The control of the camera should always be controlled by the user.

11. Allow for Trial and Error

Definition: "As much as possible, allow actions to be reversible and set up protections around potential mistakes made by users. This will help relieve user's anxiety and promote exploration of the application."[50].

With VR the users interactions with the application can have a big impact on their experience. But with big impact out of interactions with the applications also comes

a possible big mistake out of the interaction. It is therefor important to let the user reverse their action if they perform a error or mistake. This reversal option should be clear for the user to use. This will help the user to have a lesser feeling of fear towards making mistakes and errors, instead allowing exploration within the application.

3.2.2 Performance

When designing VR for an unthetered device it is crucial that the performance aspect of the HMD is high priority. Experiencing a frame rate dip through a desktop or a console may not affect the user but in VR a dip in the frame rate might cause discomfort or influence the level of immersion with the user. Having a unthetered HMD means that there are strict compute, thermal and power constraints. Having the constraints in mind from the start will ease the process to come up with a successful product.

First thing to talk about is style vs. realism. Depending on the concept of the application the realism of the graphics may not be important. It can then be a good choice to go with a more cartoon like style on the application that will not require high performance. However the application that will be developed in this project will aim to have a high realism. It is therefore important to choose the focus of the application, that is, what in the application that will have a high priority. It can for example be the level of definition of the leaves on the trees, or good reflections on the water surface. The goal is to put the time and details on the things the user will have their focus on.

With the limiting performance of a HMD there are some aspects that will be taken into extra consideration, such as the amount of triangles that is recommended on a Oculus Quest 2 is 750 000 to 1 000 000 [72]. This is the amount of triangles recommended for the whole frame. Open worlds can become costly and should be implemented with caution. Dynamic shadows need to be calculated every frame, leaving the GPU and CPU with heavy load. Many times the dynamic shadows also requires re-rendering of the scene several times within the same frame. Full screen effects, such as tone mapping and real-time ambient occlusion requires a lot of pixel throughput that can become hard for the HMD. Dense foliage might cause performance issues, therefore try to keep trees and plants statics and geometrically chunky [72].

3.2.2.1 Rendering

In all GPU's that are rasterization-based, all the triangles on the screen will output pixels that will be depth-tested against current value, on their pixel position, of the depth buffer. If the test is passed the pixels will write the new color and depth value into the color/depth attachments. This will be done over and over again until all triangles of the frame are rendered. In other words for every pixel of every triangle, the GPU have to execute for the depth testing at least one read, and then possibly two writes (depth and color) if the test is passed. The more overlapping geometry,

the more reads and writes. This leads us to the draw order of the rendering. Think of rendering the closest object first. This will lead to less overdraw per fragment, which means less write executions. As everything behind the first object that is not visible will be discarded through the depth-test. If we started with the object in the back then we had to do more than one rendering for those pixels as the closest object would overwrite that.

Oculus Quest 2 uses the Qualcomm Snapdragon XR2 with a refresh rate up to 90Hz and for each eye the resolution is 1,832-by-1,920. Qualcomm Snapdragon XR2 uses tile rendering. When creating a 3D image for a screen it is often done through executing several steps, such as loading to memory, performing mathematical functions, creating polygons and so on. For each step the memory has to hold the current part of the image, and in the end the image has become large in terms of size. This requires a high bandwidth to be able to transfer the image, however providing enough bandwidth can be a problem when there is a limitation to the power supply and a limitation of the size. Therefor the Qualcomm Snapdragon XR2 uses tile rendering instead. Instead of render the whole image at once, it breaks down the image to smaller parts, tiles. The tiles are then rendered sequentially through a fast and small cache for the reads and writes. And when the pixel have reached a final computation the value will be stored into RAM. Tile rendering can be executed since each pixel is independent from the other pixels of the frame.

3.3 Game Design

This project will take a game design approach towards the development of a VR experience with the goal to create a calming sensation for the user. Even though a game will not be developed, a game design approach may help the development of the product through providing already established frameworks that can be utilized to achieve the goal of the product. The framework that will be used is the Mechanics-Dynamics-Aesthetics(MDA) framework. The MDA framework will be looked into in the following section.

3.3.1 Mechanics-Dynamics-Aesthetics

Having design methodologies help the designer with guidance during the creative thought process that is involved in design, it also helps with assuring the quality of the work. MDA is a formal approach to understanding games and was introduced by Marc Leblanc during a workshop for game design [51]. Hunicke et al. belives the MDA framework will clarify and strengthen the iterative design process executed by scholars, researchers and developers to result in an easier way to decompose, study and design games [52]. By dividing the games into their three distinct components from a consumption view, rules, system and fun and then establishing their design counterparts mechanics, dynamics, aesthetics, see figure 3.1. Using the MDA framework one should think of each separate component as a lens that can be put on to view that aspect of the game. They are intertwined in each other as one gives rise to the other and the other way around but they are still separate.

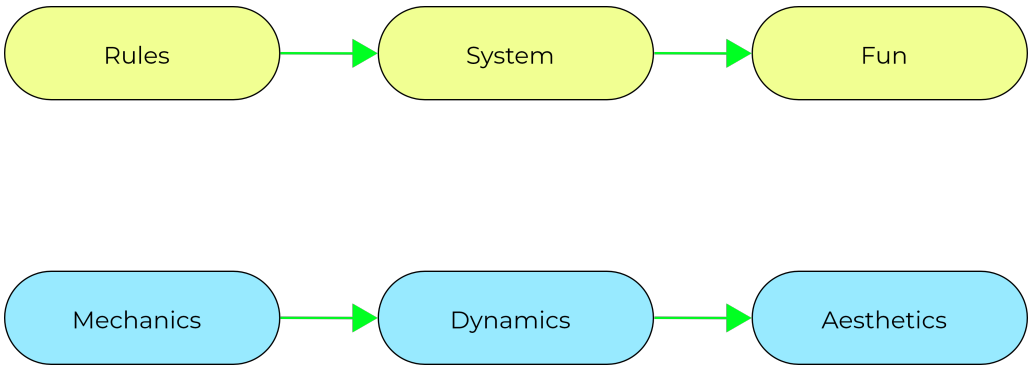


Figure 3.1: MDA framework

Mechanics is the first thing a developer encounters. This is the building blocks of the game and its fundamental core described through data representation and algorithms. Dynamics takes the mechanics and describes their behaviour when the game is running. Dynamics takes the users inputs and other users output in consideration. Aesthetics describes the desired feelings of the user that come to life when they are interacting with the game. The basic conception for this framework is that games are seen as artefacts rather than media. The behaviour of the game is what it consists of, not the media shown to the user. Therefore it is important to have in mind that it is the behaviour of the game that makes up the outcome of the game. From the users perspective aesthetics sets the feeling, and that feeling comes from the the dynamics that are observed, which in their turn comes from operable mechanics. Looking at it from the designers perspective it is the mechanics that gives rise to the dynamic behaviour which in its turn give rise to aesthetic experiences for the user, see figure 3.2.

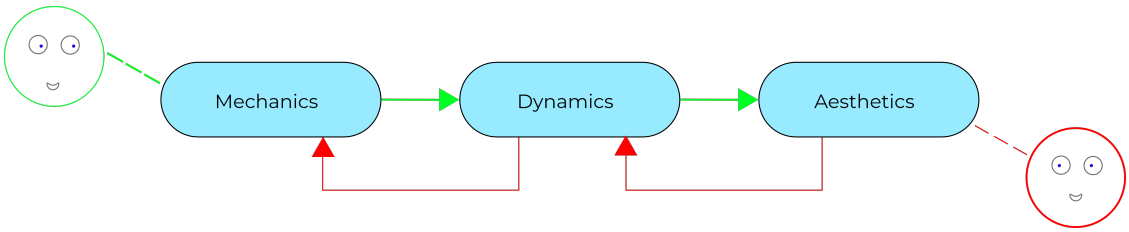


Figure 3.2: MDA user and designer point of view

3.3.1.1 Aesthetics

How do one define the feelings experienced when interacting with the game? Words such as fun can be hard to define as fun is subjective to each individual user. When describing a game using the MDA framework we are looking to use a more specific vocabulary that makes it easier to describe the aesthetic the designer looking to convey to the user. The following list contains the vocabularies presented by Leblanc [51], he describes it as "Eight kinds of fun". However the MDA framework is not limited to these vocabularies, it is only a part of it.

- **Sensation:** Game as sense-pleasure
- **Fantasy:** Game as make-believe
- **Narrative:** Game as unfolding story
- **Challenge:** Game as obstacle course
- **Fellowship:** Game as social framework
- **Discovery:** Game as uncharted territory
- **Expression:** Game as self discovery
- **Submission:** Game as mindless pasttime

Looking at a game like World of Warcraft it can be argued that it consists of the following aesthetic components: Fantasy, discovery, challenge, narrative, expression, submission. Looking at Go Fish it can be argued that it consists of fellowship and challenge, or Counter-Strike that also consists of fellowship and challenge. Each game, if containing multiple aesthetics, can prioritize different aesthetics depending on what the goal is. For example it could be argued that World of Warcraft have a heavier emphasize on narrative than on submission.

Taking advantage of the "eight kinds of fun" provided by the MDA framework it is possible to define models for gameplay. Out from these models created with aesthetics we can describe gameplay mechanics and dynamics. Taking a look at Counter-Strike and Go Fish they booth contain challenge as an aesthetics, the challenge is to defeat the opponents, Go Fish by themselves and Counter-Strike in teams. These games are achieving their goals when the player is emotionally invested trying to defeat their opponent(s). To be able to defeat their opponent(s) there must be an opponent(s) and that the opponent(s) are, like the player, trying to have their victory. Without an opponent the games would be boring, the same goes if there is not any clear winning condition and if the player can not win, leaving them with an uninterested game.

3.3.1.2 Dynamics

Dynamics are created to induce a feeling with the player, an aesthetic experience. For example the aesthetic challenge are induced by creating pressure towards the

player, such as time-limits or having their opponent making moves against them. Fellowship is created through having different players cooperate, for example having a shared goal that is easier accomplish if players work together. Narrative is created through having a story as the red thread in the game, expression through letting the player leave their mark on the game.

When talking about dynamics the goal is to be as concrete as possible. Creating models that can assist the description and prediction of the dynamics of the game. For example in a game where the goal is to reach level ten by obtaining a certain amount of experience per level, a model for the average experience obtained per hour could be used to determine how much experience is needed to level up. This can then be used to decide how fast paced the game should be. If the game have a narrative aesthetic, it is important to keep the player invested in the story, therefor it can not be too fasted-paced or too slow-paced. The average experience obtained model can be utilized to find a proper experience cap to create a narrative experience for the player.

Dynamics also assists understanding different states or changes in the gameplay through feedback systems. If we once again have our narrative game previous talked about and now have two players in it. If one player reach level two before the other and becomes so strong that they just keep on creating a bigger gap between themselves and the other player. The other player may lose its interest as they become insignificant relative to the progress made in the game. Seeing this behaviour in the game, through feedback, it could be a god idea to implement some kind of boost to the lower leveled player so they do not fall behind the other player, creating a more common feeling between the players towards the progress they make in the game.

3.3.1.3 Mechanics

Mechanics are what the player has been bestoved with within the game context. Such as actions, behaviours and control mechanisms that can be executed in the game. The mechanics together with the content in the game, such as the environment, decides the dynamic behaviour of the game. Through setting mechanics in a certain context dynamic behaviour rises. For example once again looking at Counter-Strike, which is a first-person shooting game, that contains, among others, the mechanics weapons, ammunition, health, spawning-spot, death. These mechanics gives rise to behaviours among the players, such as camping(sitting still at an spot waiting for the opponent), sniping, rushing, etc. Go Fish is a card game and have mechanics such as shuffling, dealing, betting, which can give rise to dynamics such as bluffing. With mechanics there is a possibility to tune the games dynamics. Mechanics could be used in such a way that it changes the dynamics that in their turn changes the aesthetic. Looking at the previous mentioned game with focus on the aesthetic narrative, a mechanic of having a shared experience level will take away the risk of one player getting to much advantage leaving the other player not invested in the game.

The framework of MDA provides a great tool to describe games and understand why they are appealing to the users. By dissecting the game in to the three parts of mechanics, dynamics and aesthetic it gives a deeper understanding of the game and its behaviour. Viewing the game through each of the lenses it is easier to understand why a certain feature provokes a certain feeling with the user. MDA can then be used to help decide what kind of mechanics that will be implemented to provide a relaxing feeling for the user.

4

Methods

This chapter presents the general methodological approach and the methods used to support the design process in this project as well as the methods used to gather data on the users experience in the VR. It will be divided in to four sections, first the research method. Then the design process to create a virtual nature environment. The third section will tell about the execution of the testing. Finally the fourth section will talk about the planning on how to execute the previous sections.

4.1 Research

This project will be of a exploratory research type. Exploratory research is a research that is used when investigating into a problem that has not been clearly defined. It is executed to receive a better understanding of the problem, but it will not provide a conclusive result. It is good for research purposes and collecting data, which can be good for determining if a VR nature experience have any positive effects on a human. Gaver comes to the conclusion in his research paper What Should we Expect From Research Through Design that "we should reflect on the appropriate ways to pursue our research on its own terms.", this in regards to the debate if design is or should be considered a science[56] . With this statement I think that it is important to try and see how the research can progress in its best way, using theories that can assist the research but at the same time not feel limited to the boundaries of that research-theory. So even if this research will be of the exploratory kind there will also be influences from the social research. Such as the ten rules [53] presented by Yolanda in Do It Yourself Social Research, see the following list. These rules will be used throughout the research to question the standpoint of the researcher and see if their view has changed along the way.

1. "Work out what you genuinely want to find out and what you genuinely don't know. Work out what are the questions arising from what you have noticed so far, and who you, the inquirer or inquiry group with the questions, are."

2. "Work out what your values and interests are, what you want or think is wanted and what you think is stopping you getting it now."

3. "Identify who and what the research is for: the critical reference group and its members' interests and values, as well as those you are trying to influence or

inform."

4. "If you want to know what people are doing and why, and what to try next, start by asking them."

5. "Interact, hear, listen, see, observe, question. Immerse yourself in the world of the researched."

6. "Be rigorous and then stand back and think sceptically about your observations and existing assumptions."

7. "Use your imagination and reaction to get to deeper, richer, wider understandings and explanations, and check these out as part of the research."

8. "Ask 'What else is going on here of which people may not be aware?' Step back and note the 'structures' and connections, and look at how they impinge on people, including yourself. Check out how others see these too.

9. "Good research interprets and analyses the findings of research (takes them to pieces), and synthesises (puts them together) into a new theory story. It makes explicit links between theory and evidence, explanation and description, and tells a story of how things are/were, or could be."

10. "Communicate! Act! Keep researching if you need to, as your new experimental actions begin to be able to be observed . . . now, back to Step 1 again! Generate new questions! . . "

In the Craft of Research by Booth et al. they bring up the importance of having the reader in mind when conducting research. It is important to create a role for the writer as well as the readers and to establish a relationship between the two. Thinking about the reader from the very start of the research and as it goes on, think about them again, and again, and again. This will provide a better experience for the reader and can help the writer structure the research. Booth et al. provides a checklist for understanding your readers [54] that will be used to make sure the readers are taken into account during the research.

1. "Who will read my report?"

2. "Do they expect me to do what I intend to do?"

3. "How much can I expect them to know?"

4. "How will readers respond to the solution/answer in my main claim?"

4.2 Design Process

To create the VR environment a design process will be conducted to achieve a satisfying product. The following section will describe the design process. In the theory section the overall theory of a design process was discussed, now there will be more focus on each method and how to execute them.

4.2.1 Design Sprint

The design sprint is an established methodology that answer questions quickly. It involves users in the process and goes through the steps of designing, prototyping and evaluating. Design sprints are valuable when the envisioned final product are not clear and there is questions to be answered. If features are already agreed upon and a direction towards how the final product will be, a design sprint is not necessary. However if the final product is based on weak positions and assumptions a design sprint can be utilized to make sure that the time spent on finalizing the product is well spent time and based out of valid positions. The design sprint should be seen as the beginning of generating ideas and coming up with solutions for the problem. [57].

Before starting a design sprint it is important to plan for it, such as deciding the time and goals for the sprint. The planning is done to get all the concerning parties on the same page. For the stakeholders to know what is going on, and for the design team to make sure they have the same goals and working directions in mind. The planning sets the agenda and the methods that will be used for the design sprint to help overcome challenges and achieve the goals that have been clarified. Before moving on to the design sprint the question "Do we have enough information about the challenge" needs to be asked. If answered no, then more research has to be conducted. If answered yes, then the design sprint can be started.

As seen in figure 4.1 the design sprint will consist of six different phases, *understanding, defining, sketching, deciding, prototyping* and *validating*. These six phases are grouped into three "diamonds". The beginning of a diamond means that divergence will take place, trying to broaden the view of the problem and come up with many ideas. Thereafter the diamond narrows and this means that its time for convergence. The convergence phase is where the ideas are narrowed down to the best idea that will be carried on in the design process.

4.2.1.1 Understand

The understand phase is all about broad thinking and trying to look at the problem from various angles. Exploring the problem space to achieve a broad understanding of the problem. One method to do that is through observation. Observation in a field study context, meaning that the observation is taking place in the user´s context rather than in a lab or some other facility. In this case the user´s context will be in a nature environment. The type of observation will be "fly on the wall". The "fly on the wall" is exactly like a fly on the wall, the researcher is only observing

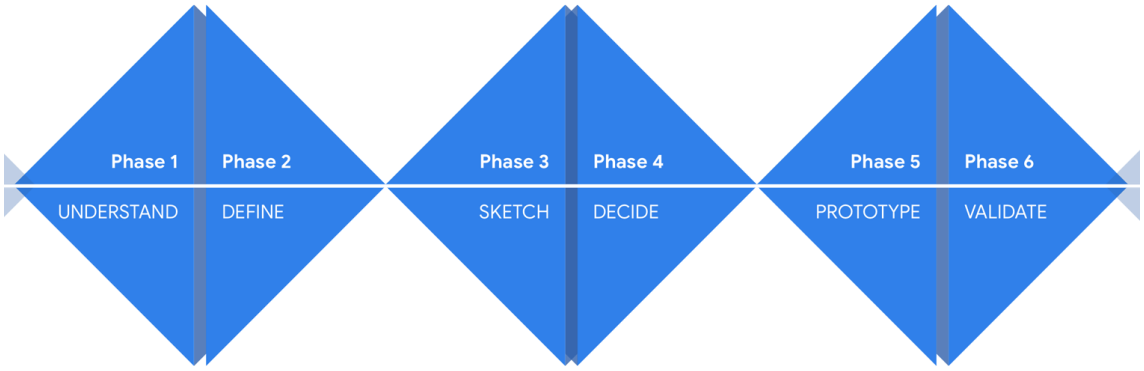


Figure 4.1: Design sprint layout [57]

the user without any interaction from a distance. The researcher takes notes of the user behaviour to gather data. This type of understanding method is good to get a grasp of the big picture, how the user actually is interacting with the environment with out any factors interfering with their behaviour.

How Might We (HMW)[58] is another method that can be used during the understanding phase. Its purpose is to transform problems into opportunities. When obtaining insights about the problem those insights can be rephrased into a positive opportunity. To do this it is critical to know the meaning behind each word in HMW. The How indicated that there is an answer somewhere, and it is for the researchers to find it. The Might tells the researcher that this solution might work or it might not work, either way is fine, as long as it is brought up and discussed around. The We empathizes the importance of the team, that the design sprint is about teamwork and many times it is about building upon other ideas. HMW encourges designers to use pen and paper, preferably sticky-notes, and write down one HMW-idea per sticky-note.

4.2.1.2 Define

During the define phase the information gathered in the previous phase is evaluated. The information is evaluated so it can be narrowed down and allows the designers to set their focus and direction for the coming phases in the design sprint. Defining the future of the design sprint is achieved through defining specific context and desired outcomes of the potential solution, as well as defining the goals, metrics and signals. Metrics and signals are both feedback that gives indication to the designers if the goal has been achieved. The difference between them is that metrics are quantifiable, numeric outputs and signals a more abstract measure that takes a general presence in the users behaviour in account. To accomplish this the method The Golden Path[59] can be used. The Golden Path is the optimal path for the user to take to discover the applications real value. An application often has many different paths that can be used to achieve a desirable goal, and even if no paths are wrong there

is often an ideal path that leads the user to their goal in an effortless way. This golden path should be the default path that the user will use. Through making use of stories about the users interaction with the product an interaction path that comes with ease and is effortless can be discovered. The goal of The Golden Path is to understand the ideal path for the product, which will help the designer focus their work.

Defining the goal, metrics and signals the method Success Metrics & Signals [60] will be used. The Success Metrics & Signals method help the designers agree on a common unit of measurement that will help the designers with their focus and the evaluation of the solutions success rate. The Success Metrics & Signals is executed through three different steps, one for the goal, one for the metrics and finally one for the signals. The following list provided by google shows the guidelines for this method [60].

1. **GOAL** Start by thinking about the big picture: What are you trying to help users do? What problem are you trying to solve?

2. **SIGNAL** Next, consider what change in user behavior or opinion would indicate you have been successful in your goals. There may be multiple signals for each of your goals.

3. **METRIC** Finally, determine how to measure the size of any change in user behavior or opinion. This could be through surveys or log analysis.

4.2.1.3 Sketch

The sketching phase is all about coming up with solutions to the problem that the designers have been faced with. The idea with sketches are to attack the problem from a variety of angels to try and find a solution within the problem space. For inspiration the designers can look at similar solutions in different problem spaces. There are different methods that helps with the sketch phase. One that is good for warm-up for this phase is the The Warm Up: Comparable Problem [61]. This method makes the designer to look at other fields or industries trying to find similar ideas that can help solve their own problem. This is method should be quickly executed and the main purpose is to boost the creativeness of the designers.

Crazy 8 [62] is another method that can be used during the sketching phase. Crazy 8 is a fast sketching method that has its power in letting the designer go beyond their first idea. During Crazy 8 the designers aim to do eight sketches that origins from eight different ideas. The time spent should be approximately one minute for each sketch. This provides the designers with many different solutions to the problem that can result in inspiration and increases the chance to find a good solution. It is important to emphasize that the sketches do not have to be beautiful, they should be a mean to communicate the idea, a way to facilitate a discussion around the idea. The sketches can also be unrealistic, a bit crazy, to spark the imagination and creativeness of the designers.

Solution Sketch [63] is a great complement to crazy 8. Through the method of Solution sketch the designer choose one idea that they consider the best one. It can also be a new idea, or a combination of previous ideas. Unlike Crazy 8 Solution Sketch let the designer spend more time articulating the idea through a sketch. The goal is to create an idea that is clear and ready to go further with. It is recommended to have at least three frames or states of the concept to assist conveying the idea. The idea should also have a name to make it more easier to remember. Multiple ideas can be brought on to the next phase, where it will be decided which idea that will succeed and be brought forward in the process.

4.2.1.4 Decide

During the deciding phase it is time to make a decision on what direction or concept to take on to the next phase and start prototyping on it. During this phase a decision-making method will be utilized to come up with one idea that will be selected to work further on. Such methods are for example heat-map voting or dot voting[64] that both lets all the members of the team put their vote on their best idea, which will lead to one idea getting most votes and therefore be declared winner. However this method is good if there are more than one person in the design sprint, therefore the method of Decision Matrix [65] will be used. Decision Matrix is a tool to help evaluate ideas based on two different parameters that are closely related to the final goal of the product. Often these parameters takes the value for the user and the technical difficulty in consideration, see figure 4.2. The matrix help clarify the value of the ideas, and ideally the designers are looking for high user value / low technical difficulty or high user value / high technical difficulty.

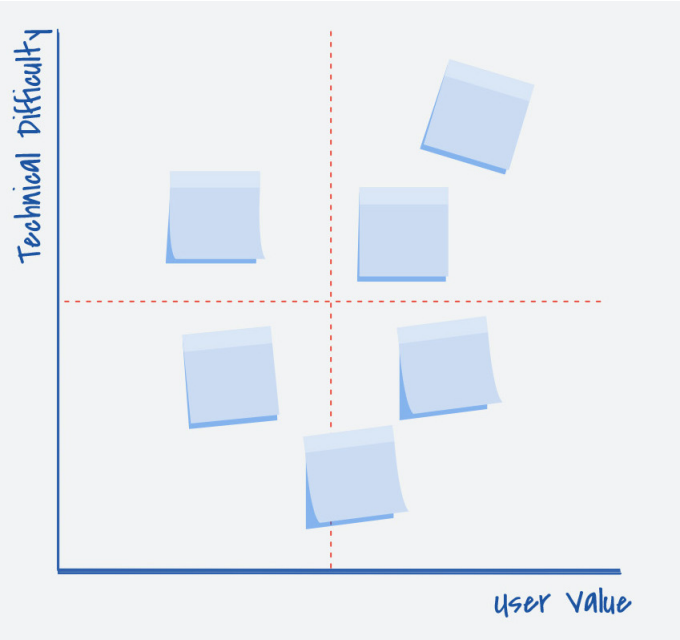


Figure 4.2: Decision Matrix [65]

4.2.1.5 Prototyping

The prototyping phase means that it is time to put the concept into a prototype. This is when the concept emerges and takes a purer form. Decisions will be made during the prototype phase that will shape the product. Prototyping in the design sprint context means low-fidelity prototyping. The goal here is to create a good enough prototype to answer the questions that have been formulated. It often takes the sketch that has been previously made and makes a facade of it. This to get an authentic response out of the users when executing the validation phase. Therefor it is important to be selective with what is chosen to be a part of the prototype. It is a good thing to know the flow of the product so the important steps in the product can be prototyped to answer the questions the designers have. The key here is to put focus on the right things, there is no need to put focus on back-end when that will not affect the validation of the prototype in any means.

4.2.1.6 Validating

The final step in the design sprint is validation. It is now time to validate the concept that has been brought forward. To do this user-tests will be conducted, where the user will provide feedback on the prototype that has been built. This can be done through the method of usability study. This method is good to receive feedback in regards to the users satisfaction towards the concept as well as the users usability issues. The user will get one or several tasks that they have to accomplish and the user will also be asked to think out loud while they are trying to accomplish their task.

This is the end of the design sprint and it has hopefully brought some answers to the concept that is being developed, or pinpointed flaws with the concept that can be worked further on. The result from the design sprint will be taken on to the next step in the design process which will be designing a low-fidelity prototype of a nature virtual environment.

4.2.2 Creating the virtual environment

After the design sprint has been finished and a concept has been produced it is time to move on to the second iteration of the design process. In this iteration there will not be a understanding nor a defining phase as a part of the process. Rather it will go directly to the sketching phase with the knowledge obtained from the validation that was executed in the previous iteration. After the sketching phase there will be a low-fidelity prototyping and then a validation. For the prototyping, and for creating the VR, the application Unity[66] will be used which will be covered in the following section. When designing the prototypes the MDA framework will be in kept in mind as to reach the desired aesthetic. After the second iteration a third iteration will be performed with the same layout as the second iteration. The only difference is that the prototype will be of high-fidelity to get a more accurate feedback towards the final product.

4.2.2.1 Unity

Unity is a cross-platform game engine with a built-in integrated development environment(IDE) produced by Unity Technologies. It supports over twenty different platforms, such as mobile platforms, desktop platforms, console platforms, web platforms, extended and virtual platforms. Unity is one of the leading applications on the market for game development. Over 50 percent of games across mobile, PC, and console were made with Unity [67]. Unity uses the programming language of C# that was made by Microsoft.

This application was chosen because of the developer of the project have previous experience with Unity and C#. As well as it is widely recognized as one of the best applications to create virtual environments. It also supports Oculus Quest 2, which is the HMD that will be used, making it a good choice. Research about the other major contender in the top applications for VR development, Unreal engine[68], was conducted. But since there was previous experience and knowledge with Unity, it made it the application to go with.

As previous mentioned in the theory section, performance of an HMD is limited and certain steps has to be taken to end up with a smooth running application that still holds high quality graphics. These different methods that will be utilized in Unity will be discussed in the following paragraphs.

4.2.2.1.1 Level of Detail Level of detail (LOD) describes the amount of detail an object will have based on the distance of the viewer. There are three different level of details, 1, 2 and 3. For each level there is a predetermined model that defines the amount of geometric detail they have. As the viewer comes closer to the object the detail will then increase. Often objects that are further away from the viewer are not of high interest and is therefor not necessary to contain a high level of detail. Lowering the quality of the object will free up memory and allow for other objects to take more place.

4.2.2.1.2 Aliasing Aliasing is when lines have the appearance to be uneven. The line will look like a staircase, not at all looking like a straight line. This phenomena occurs when the output from the graphic device can not display that high resolution for a straight line. To prevent this there is a a method called anti-aliasing. Anti-aliasing helps smoothing the edges of objects by taking the jagged lines and mixing them with the colour of the surrounding pixels. This will take away the aliasing but it will instead cause a blurrier image around the lines.

4.2.2.1.3 Shadows Shadows are important to obtain a depth in the scene, however shadows can be very computational intensive, especially for mobile devices. Therefor it is necessary to be careful about shadows when developing a scene. Such as making the shadows static, which means that the shadows are precomputed and will not take up extra computational power during the run time of the scene. Shadows comes out of the lightning in the scene. Lightning is a complex topic. There is many possibilities to modify it after desire. In this application the performance cost

will be of high importance as well as the quality. To do have good lightning quality with low performance cost baked lightning will be utilized. With baked lights Unity performs the lightning calculations before hand and saves the data to the disk. During run time the application loads the precalculated data and uses it to light the scene. As the lightning is precalculated no calculations need to be executed during run time, which lowers the performance cost.

4.2.2.2 Evaluating

The evaluation of the prototype will be conducted through an user-test and then with an individual interview to get feedback about the users experience. Five user tests with five different individuals will be conducted. According to Jakob Nielsen the best results come from testing no more than five users [55]. Yolanda brings up some key points for an individual interview [69]. The first is that an interview is not a one-way communication, it is a communication from both the interviewer and the participant. The interviewer will communicate her self through language, cloths, age, voice, reactions, movements etc. which might cause bias in the answers. Even if there is no such thing as a neutral language, age, voice etc. it is important to have this in mind and try to bring your self in such a way that it will assist the interview. It is also important to have good questions. The meaning of good questions is that the interviewer knows what they are looking to get as an answer. They should also be easily comprehensive, not trick-questions. The interviewer should be a good listener, paying attention to the responds of the questions and not getting ahead of themselves making conclusions. Finally during the interviews a recording will be made that can be transcribed later on to text. Using a recorder instead of taking notes will leave the interviewer with more attention on the interview and provide a more fluid execution.

4.3 Testing a VR nature experience

Testing the effects of a VR nature experience will be conducted first through a questionnaire. The questionnaire seek out to answer if a view from the nature virtual environment can cause a relaxing feeling with the participants. As well as to see if different quality in the graphics will have an impact on the users. The questionnaire will contain images from the VR that the participants will answer, based upon the Likert scale, regarding their feelings towards the statement "Relaxing", "Worried" and "Uneasy". Five possible answers will be available, in a linear fashion the first answer will be strongly disagree and the last answer strongly agree. This will provide with quantitative data. The questionnaire will consist of a mix of computer generated images of nature in different quality, the actual nature and images that can be experienced as stressful. Finally the participants will give additional feedback on their thoughts towards the images.

Secondly there will be users-tests with the goal to find out if a virtual nature environment can cause a relaxing effect on the user. Not necessarily with the same users as before. The test will use Profile of Mood States (POMS) as a measurements of

their experience. POMS is a psychological rating scale used to measure transient and distinct mood states. It was developed in 1971 to help assess mood states with individuals by Mcnair et al. [79]. The POMS measure six different moods, anger, confusion, anxiety, vigor, depression and fatigue through having the individual answer a questionnaire consisting of 64 questions or 32 question, also known as the long POMS and short POMS. Each question is an adjective and is related to a mood, and only one mood. The questions are answered in a Lickert scale of five answers, with each answer having a value from zero to four. A Total Mood Disturbance (TMD) score will be calculated out of the answers through adding the negative-mood related questions, such as anger, confusion, anxiety, depression and fatigue, and subtracting the positive-mood related questions, vigor. A study performed by Katja et al.[80] on German population shows that a POMS consisting of 16 question provides almost as good as a result as the POMS with 35 questions. The questionnaire will consist of around 20 question evenly distributed between the different moods.

The user test will first have the participant go through a POMS. Then the participants will be equipped with a heart rate monitor. Heart rate may have the potential to measure stress levels [71] and it will therefor be monitored to get data that may provide a answer to the sought for question. The heart rate monitor that will be used is the Polar verity sense [81]. Polar verity sense uses optical heart rate monitoring through a method called photoplethysmography. This technology uses light pulses to measure the heart rate by measuring the amount of light that is scattered by the blood flow in the body. The heart rate monitor will be placed on the arm, either on the upper or lower arm depending on the preference of the participant. The participant will then put on the HMD and enter a VR environment that surrounds them with nature. After the ten to fifteen minutes in the VR experience the participant will first answer a question on how they feel while still in the VR environment. Then they will leave the VR by taking of their HMD. Once out of the VR the participant will once again answer the same POMS as before the experience. After the POMS have been answered the participant will participate in a semi-constructed interview. The data that has been collected will then go through a thematic analyze to find patterns that can provide insights.

The following factors may have a impact of the test and needs to be considered in the analysis:

- The ambient temperature, noise level and humidity
- The amount of sleep the participant had before testing
- The participant's emotional state
- The medication the participant may be taking
- The time of day
- The participant's caffeine intake
- The time since the participant's last meal

- The participant's prior test knowledge/experience
- People present
- The personality, knowledge and skill of the participant

The following factors will be taken in consideration to provide a reliable and valid result:

- Use competent and well-trained testers
- Test run the test to find flaws and make the tester comfortable
- Make sure the participant understands exactly what is required of them
- The test procedure should be standardised in terms of administration, organisation and environmental conditions
- The test should be designed so that another trained tester can easily repeat it
- The test should be fully documented so that it can be administered in the same way the next time it is conducted

4.4 Planning

4.4.1 Kanban

To help structure and improve the work flow during the project a Kanban approach will be taken. Kanban is a way to keep track of tasks that have been done, are being worked on to become done and tasks that are waiting to be worked on. It is a good system to maximize software development, especially to find bottlenecks in the process that slows down the production. However when working alone the major benefits of Kanban is to help with keeping track of the work flow. The web-application Trello[70] will be used to set up the Kanban system.

4.4.2 Gantt

The planing of the project was done with the help of a Gantt schedule. The project is divided into three different sections that will be conducted one after the other, and one part that will be worked on during the whole project. The three sections will be in the following order, firstly conducting research, secondly designing a virtual environment and thirdly conducting tests and evaluating them. Project writing will be conducted during the whole project besides the three sections. See figure 4.3 for Gantt schedule.

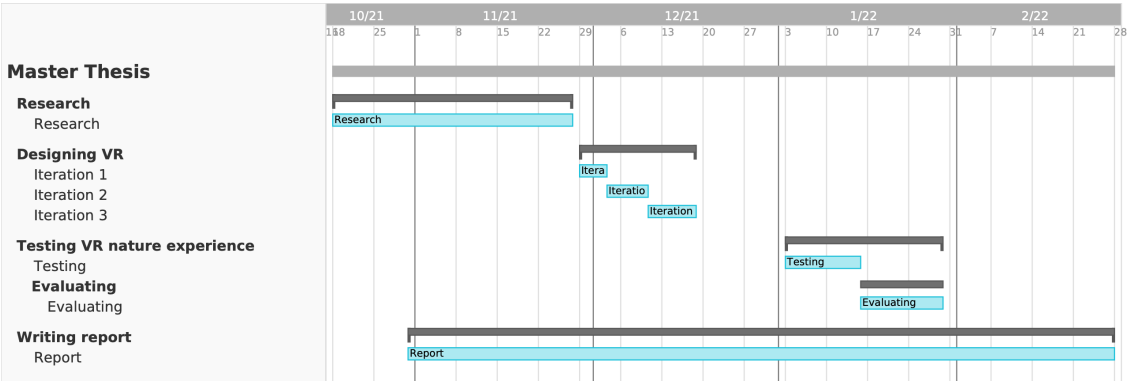


Figure 4.3: Gantt schedule

4.4.3 Ethics

When conducting tests or evaluations with persons participating the first thing that is prioritized are the participants. All user data will be handled according to GDPR. It is important for them to feel safe and that they can have trust in the tests and its administration. This is done by following four principles. The four principles are protecting the participants interests, having their consent, avoiding falsification and to make them feel welcomed. In the first step of the tests the participants are informed about the goal of the test and why it is done. Their consent are established and they receive information that they have the right to leave the survey whenever they want. It is also made clear that the data that are collected will be anonymous so their names are not to be shown anywhere in the report. The data are never stored on a server or sent over a network. The only person who had access to it is the creator and executioner of the tests.

Users that have dysfunctional parts of their bodies will be taken in consideration. The design will be conducted with the physical abilities of the users in consideration with the goal to make the application available for most of the users. During the VR testing the participants will be informed about tips to prevent sore eyes, such as remember to blink. They will also be informed about motion sickness that can occur in VR. The HMD will also be attached in such a way that it does not put constrains on the eyes or causes any physical inconvenience for the participant.

Covid-19 is a factor that will be taken in consideration. The recommendations of the Swedish public health authority will be followed. Even if they do not recommend the use of face mask or one-time gloves the participants will be asked if they prefer these items to be used during the interactions. Hand sanitizer will always be present.

5

Process and Execution

5.1 Iteration 1

5.1.1 Define

5.1.1.1 The Golden Path

The golden path of the application can be viewed in figure 5.1. It starts from the point of the user already have attached the HMD and are in the VR ready to start the application. The golden path begins with the user launching the application. Secondly the user enters the virtual nature environment by choosing an available option. Thirdly the user experiences the virtual nature environment on a preferred time. When they are satisfied the user quits the application and feel more relaxed and in a better state of well-being.

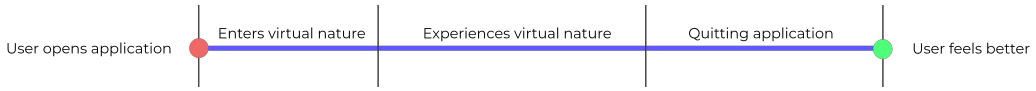


Figure 5.1: The Golden Path

5.1.1.2 Success Metrics & Signals

The method of Success Metrics & Signals helps to put focus on what is important in the design process as well as help measuring the success rate of the product. In the following list the outcome of this method can be viewed. The goal of the project is to alleviate the users of stress to help them reach a better state of well-being. This is done with the help of a HMD that will create a sense of presence for the user within the virtual nature environment. The signals that will determine the degree of success in the product is the users own subjective feeling towards their well-being. Their feelings after the virtual nature experience will be recorded with the help of an interview and a questionnaire taken before and after the test. The heart rate of the users will be recorded, in particular how fast the heart is beating and if it is increasing or decreasing. The heart rate will be monitored with the aid of a heart rate monitor. Lastly the breath of the users will be observed. This will be observed by the tester and only remarkable changes will be recorded, such as heavy fast breathing or calm and deep breathing.

1. **GOAL** Help the user to relax and reach a better state of well-being through a virtual nature experience.
2. **SIGNAL** Subjective feeling of the well-being of the user, the users heart rate and the users breath.
3. **METRIC** Interview and questionnaire for the subjective opinion and heart rate monitor.

5.1.2 Sketch

5.1.2.1 Crazy 8

During the sketching phase the method of Crazy 8 was used. Eight different sketches was produced, that can be seen in figure 5.2. All the eight sketches are quite similar to each other with some different concept that do them apart. They all come from the same concept of experience a virtual nature environment, but a few of them explored different settings in regards to the nature. For example, an environment based on the African savannah, a world beneath the surface in an ocean environment or among the forest with mountains and lakes. Different means of exploring the environment was produced, such as walking around the environment, sitting in a chair teleporting to different locations, swimming in the water or flying across the sky taking in the world beneath.

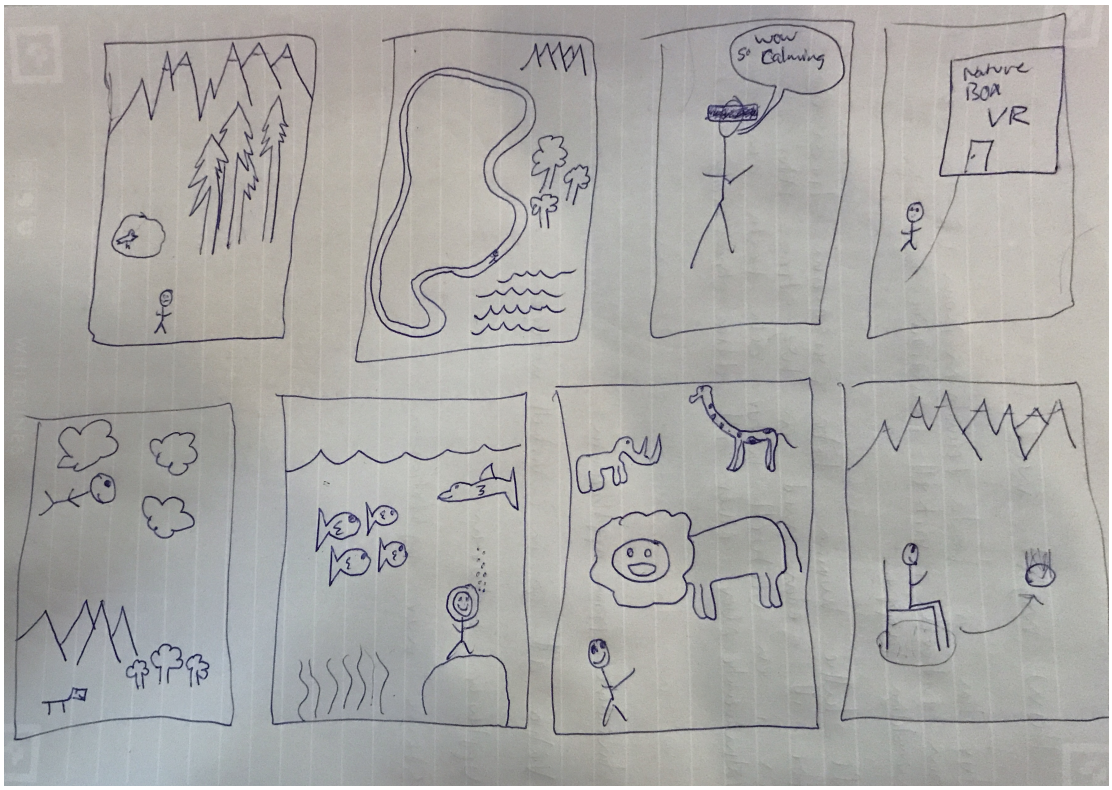


Figure 5.2: Crazy 8

5.1.2.2 Solution sketch

Two solution sketches were produced, which can be seen in figure 5.3 and figure 5.4. The first, two worlds, explores the possibility to have two different world, one above the water surface and the other beneath. Having the user choosing which world they want to be in by simply walking into our out of the water. The world would contain animals both above and underneath the water surface. The other, forest bath, is a forest with mountains and water. This world has a path that the user will follow along to explore the nature environment. Through the path they will explore the forest world and see all its riches.

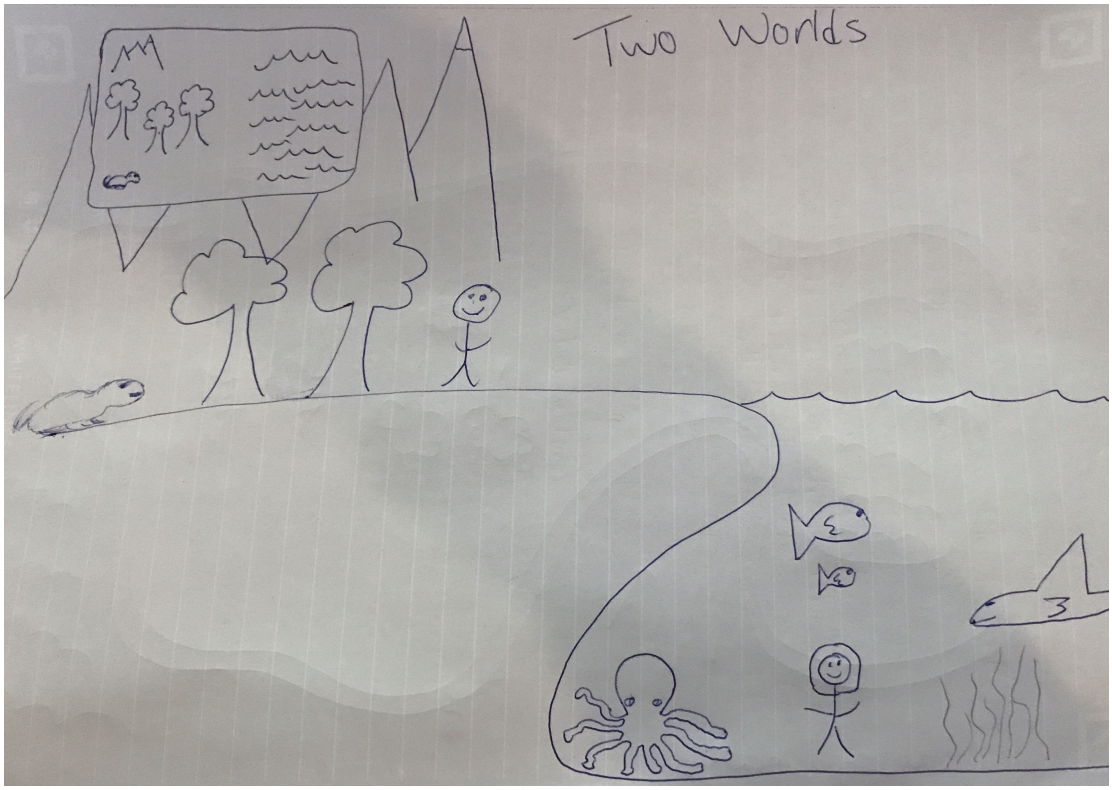


Figure 5.3: Solution sketch: Two worlds

5.1.3 Decide

5.1.3.1 Decision Matrix

With the help of the decision matrix a decision came into place. Placing the two different ideas on the graph of the decision matrix it became obvious which idea to go with. Both the forest bath and the two worlds was seen as having similar user value. They both convey a relaxing nature environment to the user. With the two worlds however the user could also choose to go under water which could provide a increased user value, especially for some user who already have a positive mental model towards the world beneath the surface. With this extra feature of the two worlds idea comes a higher technical difficulty. Having to implement a ocean environment and having the user swim around in it placed the two worlds idea higher

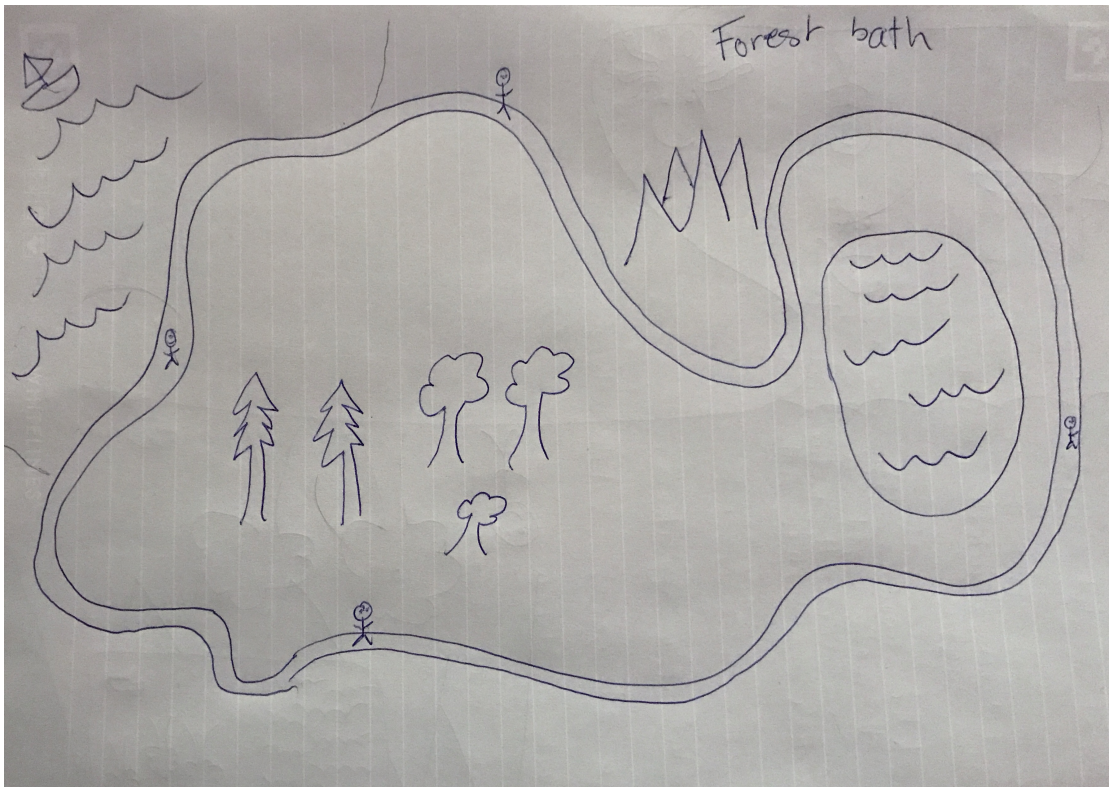


Figure 5.4: Solution sketch: Forest bath

in technical difficulty compared to the forest bath. Both the ideas are considered to have similar user value. Due to to lower technical difficulty the forest bath was the idea that was chosen.

5.1.4 Prototype

The prototype was made through simple sketches with paper and pen. The idea was to convey to the user the feeling of walking around in a VR on a path in a forest environment. Different aspects of the environment was a part of the prototype to be able to convey the views the user will see. The idea of transport on a path was also conveyed. The prototype was similar to the solution sketch: forest bath and through the means of words and sound the setting was explained for the user.

5.1.5 Validate

5.1.5.1 User-test

The user test was conducted with the help of the prototype. Five users were asked to provide their opinion on the design and idea. Five separate tests with five different users were executed. With focus on how they would perceive a nature environment as the one in the prototype, if it would be relaxing for them or if they preferred other environmental features. The idea of the user traveling on a path was also examined. By showing the prototype and explaining the concept for the users they elaborated

on their thoughts towards the ideas. In the end of the test they were asked to summarize their thoughts and feelings towards the prototype. Each user-test was noted so the data that was gathered could be returned to and analyzed.

The outcome of the validation were that the user perceived the prototype as positive. The nature environment were pleasing to the user and they thought it could have a relaxing effect on them. The thought of transporting on a path had a mixed outcome where the majority thought it was a good idea but there was also opinions that thought it would be nice if one could roam freely in the nature environment.

5.2 Iteration 2

Iteration 2 started off with a quick sketch of an overview of the scene that would be created. A minimalistic approach was taken in this low fidelity prototype with a focus to test different features. Such as the means of transportation and a path that has the role of helping the user to navigate in the environment. Other features that were implemented were trees, lake, ocean and mountains. This features were obtained through different 3D-objects that were inserted, such as planes and cubes, which sizes was manipulated to resemble the wanted feature. Colour were added to resemble the object out of the users mental model. Locomotion systems were implemented providing the user with either a teleportation mean of transporting them in the VR or a continuous movement that would transport them. Teleportation using a button on the controller and the continuous movement a joystick on the controller. For turning the user was provided with both turning their heads or a continuous turning through a joystick on the controller. Hands were implemented in the VR to stay at the same position as the hands holding the controllers position outside VR to help reduce motion sickness. The design can be viewed in figure 5.5 to figure 5.8

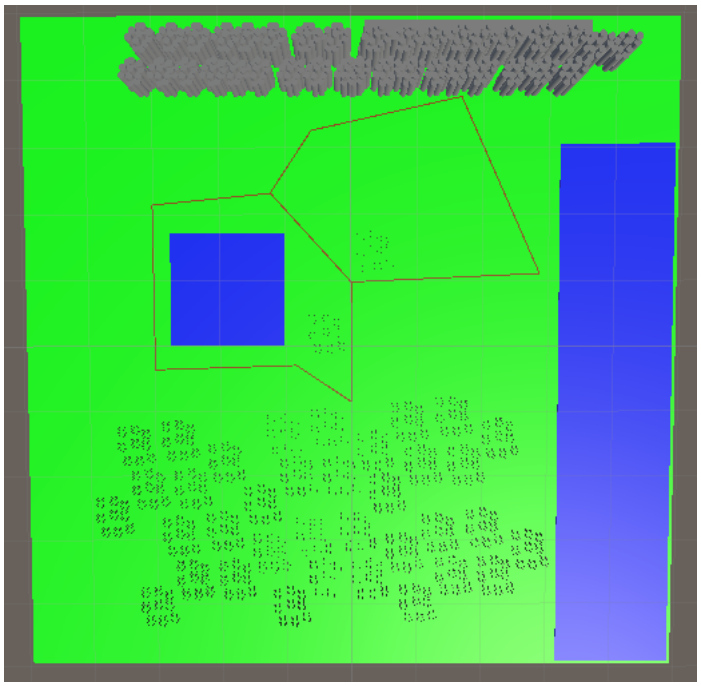


Figure 5.5: Low Fidelity: Overview

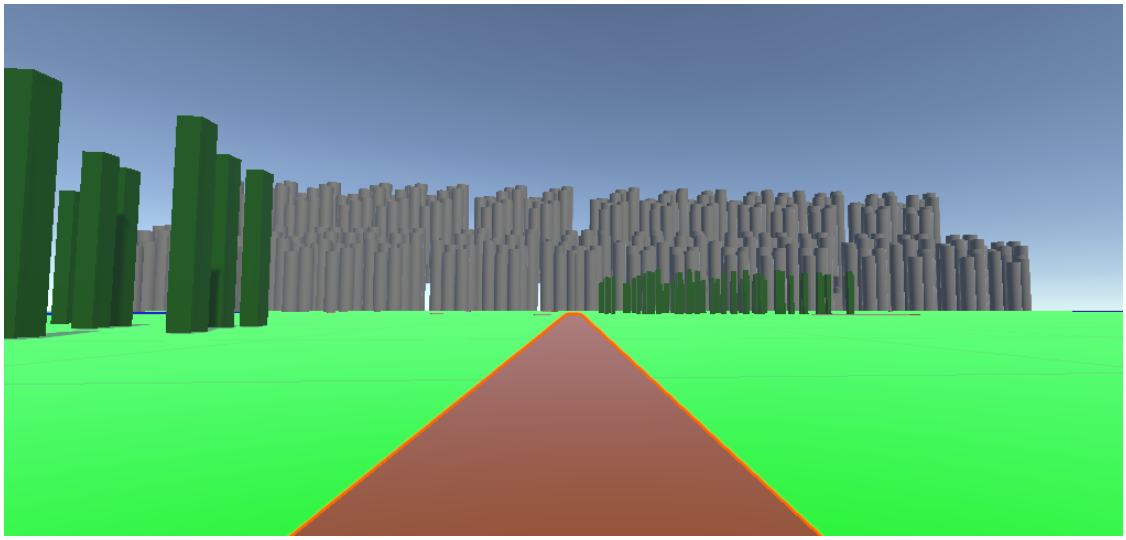


Figure 5.6: Low Fidelity: Path

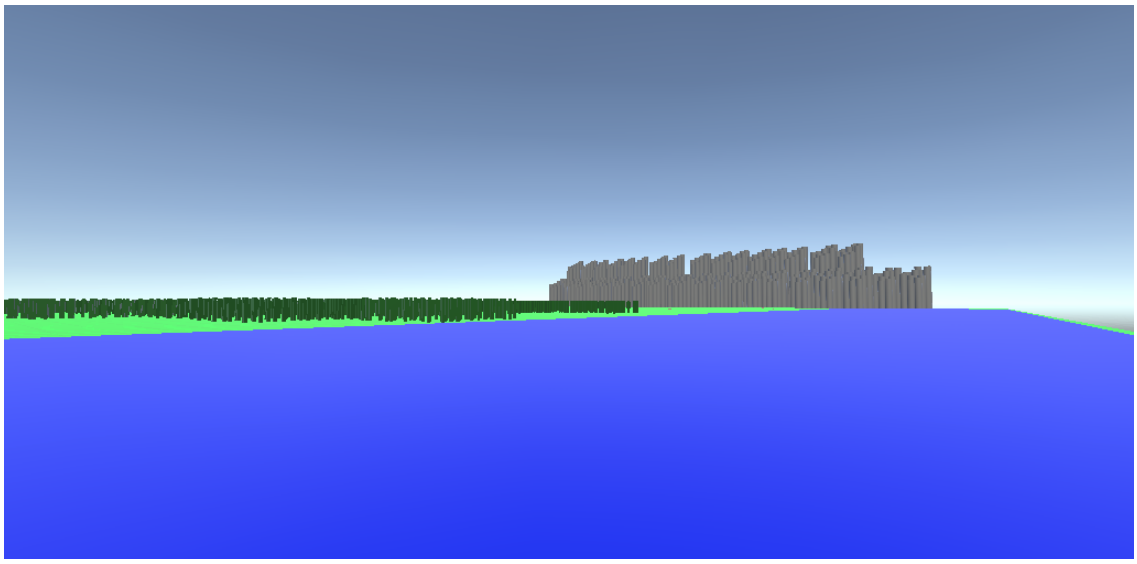


Figure 5.7: Low Fidelity: Ocean

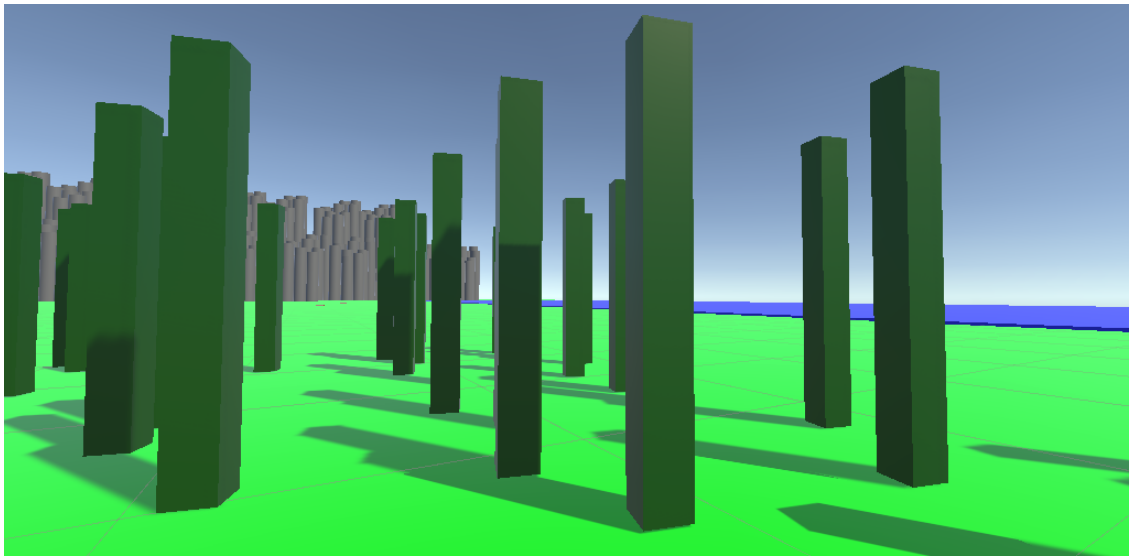


Figure 5.8: Low Fidelity: Trees & Mountains

5.3 Iteration 3

The third iteration aimed for a higher low-fidelity prototype. The same features as from the low-fidelity prototype were implemented. Different assets were used. Such as Unity's standard assets [73]. This asset provides textures for the ground, trees, water and more. A terrain was inserted in the scene using Unity's built in feature terrain [74]. This feature allows the designer to manipulate the landscape through different means, such as rising or lowering the terrain, adding trees and grass and painting texture to the terrain. It also optimizes built-in Terrain rendering for optimal performance. The result can be seen in figure 5.9 to figure 5.10

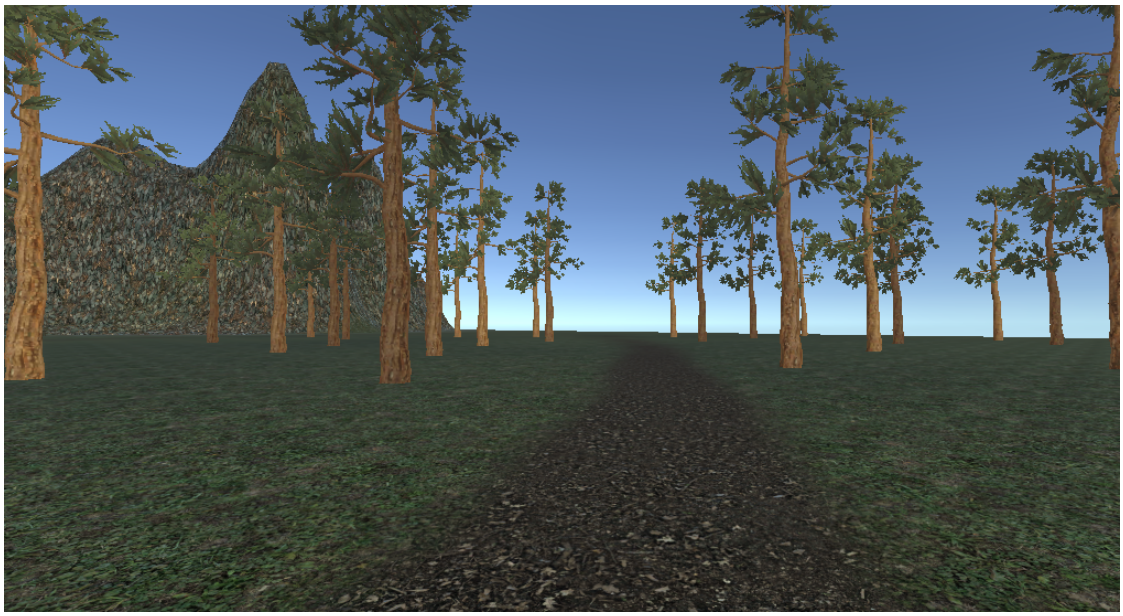


Figure 5.9: High Low-Fidelity: Path

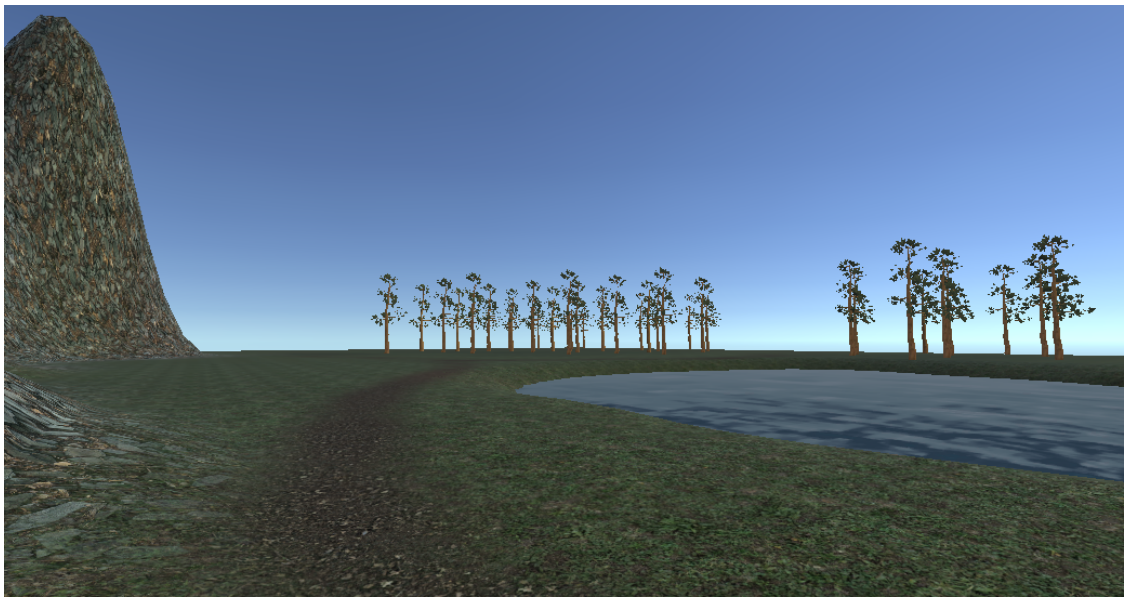


Figure 5.10: High Low-Fidelity: Lake

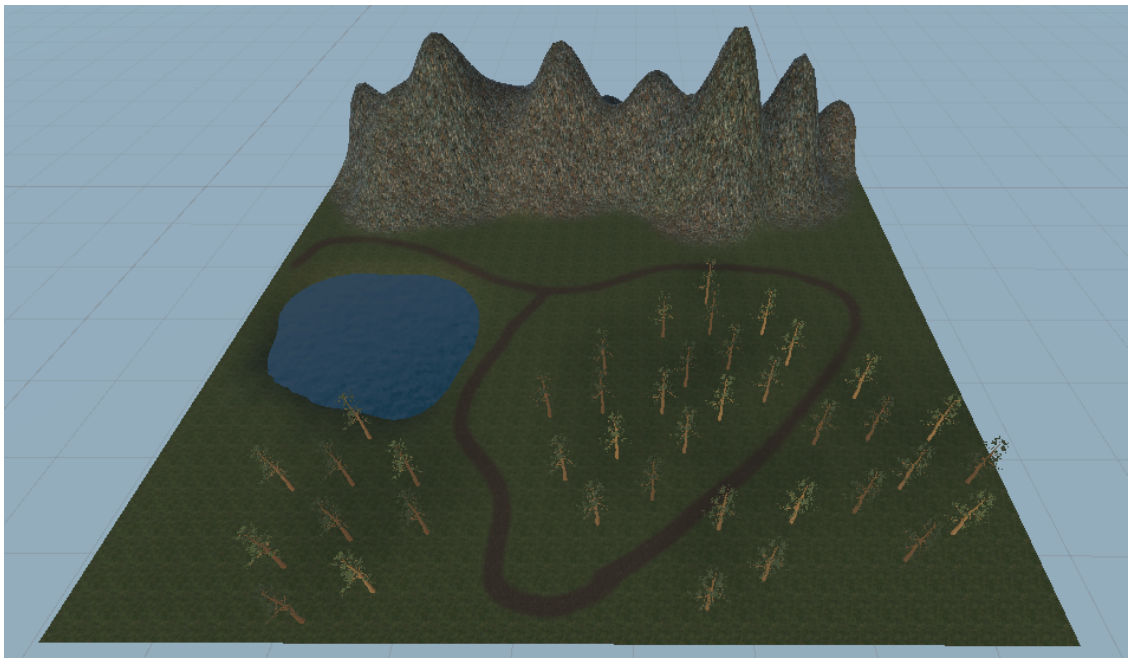


Figure 5.11: High Low-Fidelity: Overview

With the following settings for optimal performance.

- **Multithreaded Rendering:** Generates intermediate graphics commands by the main thread. The render thread converts them into low-level platform API graphics commands.
- **Static batching:** A draw call batching method that combines meshes that do not move. They are combined so they can be rendered together.
- **Dynamic batching:** A draw call batching method that batches moving objects to reduce draw calls.
- **ARMv7:** This will turn the application into a 32-bit application.
- **IL2CPP:** The Scripting Backend will be set to IL2CPP. This bakes all the C# code into C++ native code for a faster run.
- **Multi-View:** The stereo rendering mode will be set to Multiview instead of Multi pass. Multi pass render each eye independently, which requires everything to be done twice. Whit multiview the draw calls are half the amount of multi pass, since it renders both eyes at the same time.
- **Quality: Medium** The quality is set to medium.
- **Anti Aliasing:** 4x Multi sampling will be used, as it is inexpensive on the GPU in performance and the quality reduction is insignificant [75].
- **Shadows** Will be set to hard shadows only.

- **Lightning** Lightning will be baked and use a subtractive mode, which is good for low-end hardware. The lightmap size will be set to 4K

The scene produces 120 batches, 57 000 triangels and 45 800 vertices and when built and running on the Oculus Quest 2 there is a FPS of 50 with some fluctuations to it, where the goal is a stable 72 FPS. Through the OVR metric tool [76] there can be seen that the performance bottleneck is within the GPU as the utilization of the GPU is constantly at 99, while the CPU is around 30. To fix the bottleneck certain tools within unity was utilized. The first one is the profiler. Through the profiler tool we can see what happens in each frame. More exactly the workload that is put upon the CPU and GPU, and what type of work they are performing at each millisecond(ms) of the frame, see figure 5.12. It was seen in the profiler that the application is GPU bound, that means that the GPU is the bottleneck in this application, which also was obtained from the OVR metric tool. For every 60 frame there is a spike in the computational time for the CPU reaching over 20 ms, this is due to the editor loop and will not be a part of the final build. Rather the cause of the high CPU computational time is due to two threads called Gfx.WaitForPresentOnGfxThread and Semaphore.WaitForSignal which means the CPU has to wait for the GPU to finish its computational work before it can carry on. Using the frame debugger of Unity we can obtain information about how each frame is built, what kind of draw calls it makes and in what order they are performed. This however does not provide any solutions to the problem, instead we use Unity's Profile Analyzer and see that both the threads previous mentioned uses on an average eight ms for each frame. Using the Profiler once again we can see that the GPU uses 90% of its total amount of time on each frame to draw opaque objects.

Trying to change the scene by deleting all the trees does not affect the performance greatly. But the wait time for the CPU is now underneath four ms. Changing the terrain to be of the same texture neither does change the performance. However after seeing through the frame debugger the old terrain textures are still part of the draw calls even though they are not painted on the terrain. After deleting the unused terrain textures we do not have any wait time from the CPU towards the GPU and the FPS stays steadily on 72 FPS. However the utilization of the GPU is some times above 90, as seen through the OVR metric tool. During this high fidelity prototype high quality assets were used to resemble the real nature to a high degree, such as scanned assets with high resolution. However this might be a cause of the poor performance which will be taken in consideration for the fourth iteration.

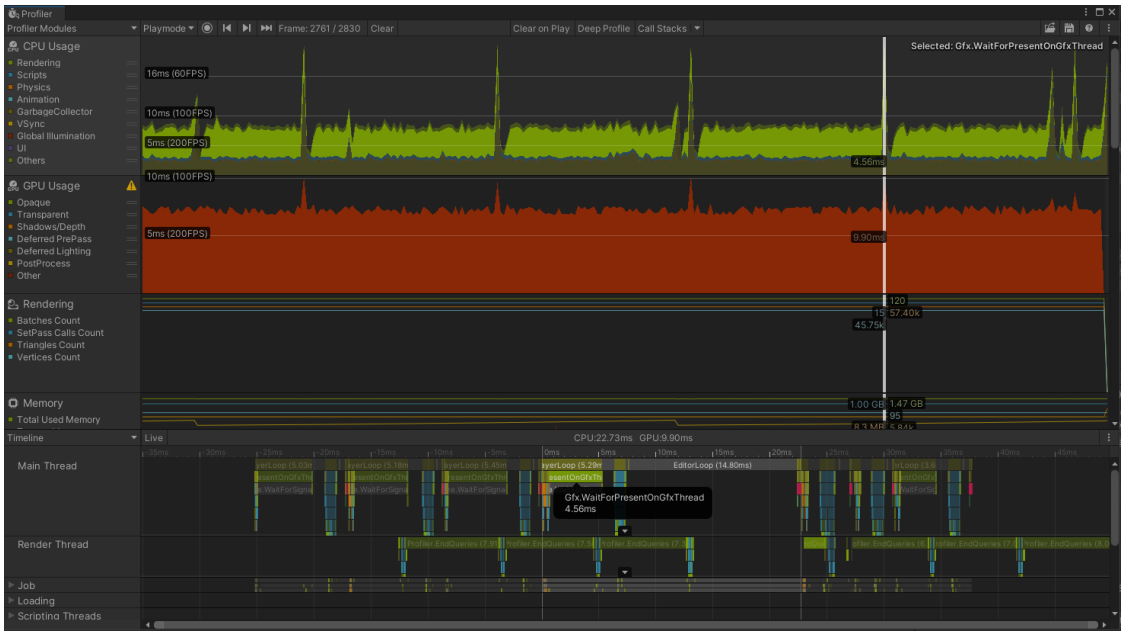


Figure 5.12: Unity: Profiler

5.4 Iteration 4

During iteration 4 the building of the environment start over from scratch. Building the scene with extra caution to keep a low workload for the HMD. Through the creation of the scene it was constantly tested on the Oculus Quest 2 to see if there was a performance issue. As well as the performance analysing tools, such as the profiler, OVR metric tool and frame debugger. The objects that are used have a low triangle count to make it easier for the GPU to render them. Different methods in showing the objects were tested, such as using Unity's billboard system to show the objects in a more simpler way when they are further away from the camera. Instead of drawing the object in full detail it is replaced with a 2D billboard representation. Trying to optimize the scene in such a way that it provides appealing environment but still is manageable by the hardware of the HMD. The result can be seen in figure 5.13 and figure 5.14.

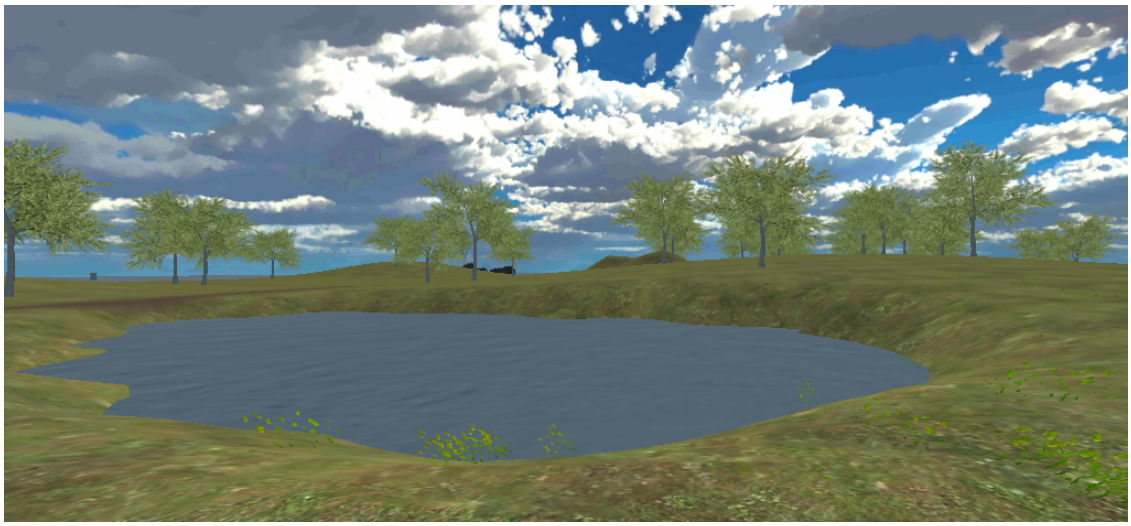


Figure 5.13: Lake

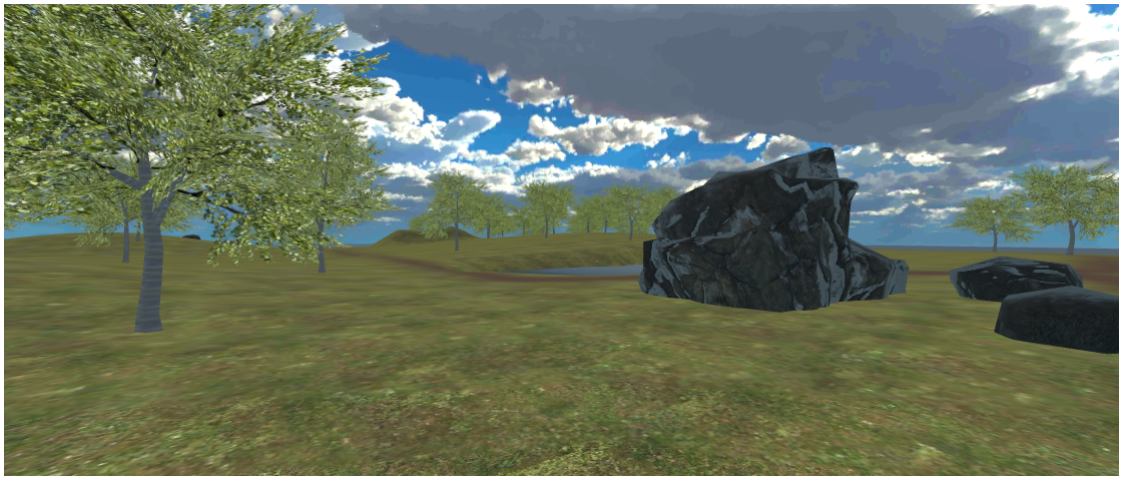


Figure 5.14: Tree and rock

5.5 Iteration 5 - High definition VR

Due to the limitations of the hardware of the HMD it was decided to provide the HMD with a cable and instead run it as a thetered device. The reason behind the decision was that providing a high quality in terms of the object will enhance the experience and make it more similar to a real nature experience, hopefully leading to a better outcome in terms of a relaxing influence on the user. The application was still developed in Unity with the results from the previous iterations in consideration. The asset package Forest Environment - Dynamic Nature [77] was used. It provides scanned 3D-objects, meaning that the 3D-objects are based upon real-world objects that have carefully been analyzed to collect data about the object so it can be reconstructed in an virtual environment. This type of 3D-objects provide high definition with a realistic look to them. Sounds was added provided by the Unity asset Nature - Essentials[78] The environment contains different sounds connected to different objects. Such as the river has a river sound and the waterfall a waterfall sound. There is also a global sound of forest sounds, such as the wind rustling through the leaves and bird song. The local sounds connected to an object are sound loops of six seconds, while the global sound has a loop of 30 minutes.

Teleportation is used as the means to transport the user. By pushing the joystick of either the left or right hand controller up, which will result in a curved ray appearing that the user can point towards the desired teleportation location. Providing visual feedback through showing the ray in two different colors depending on if it is possible to teleport to the are where the ray is directed or not. It is possible to teleport all over the environment but only on the ground, it is in other words not possible to climb rocks or other 3D objects.

Building the scene we start by importing the the necessary assets for the project. Then a terrain object is created and a desired size of the terrain is set. The terrain is provided by the asset package Forest environment - Dynamic Nature which comes with a example scene. This scene is then modified to match the desired look, how it was modified will be explained now. To get a better feel for the scales of the scene a cube-object is created so one can relate to it during the building of the scene. Then we set the texture of the terrain, as we are building a forest, leafs will be the main texture for the ground. Then we set the topography by using the tools provided by unity, lowering and raising the ground to a desired look. Then we add more textures to the ground, soil, wet soil, rock, sand, moss, roots, grass to make it more diverse and realistic. After adding the texture on top of the leafs we polish the textures with some leafs again to make it a good blending with the textures. Roads, lake, waterfalls and rivers is provided by the nature manufacture asset. Then we add slope objects where there is a high angle in the terrain. Then we add trees in varies sizes in to the terrain, trying to keep light coming through the trees providing shadows to the ground. Then we add rocks to the scene in different sizes. Then the roots are added in connection with the trees already in place, as well as branches, logs and stumps. Then we add smaller plants, such as ferns and grass. Extra leaves, branches, logs and stumps are added in areas that are a empty. Then we add mushrooms and bridges in to the scene. Finally we add particles,

such as dust flying around in the air. During the whole construction of the scene it is important to have in mind the different colors, how the objects that are placed match the context it is placed in. It is nice practice to have some contrast in the scene, such as placing white bright mushrooms in a dark shady area.

Figure 5.15: Overview HD nature

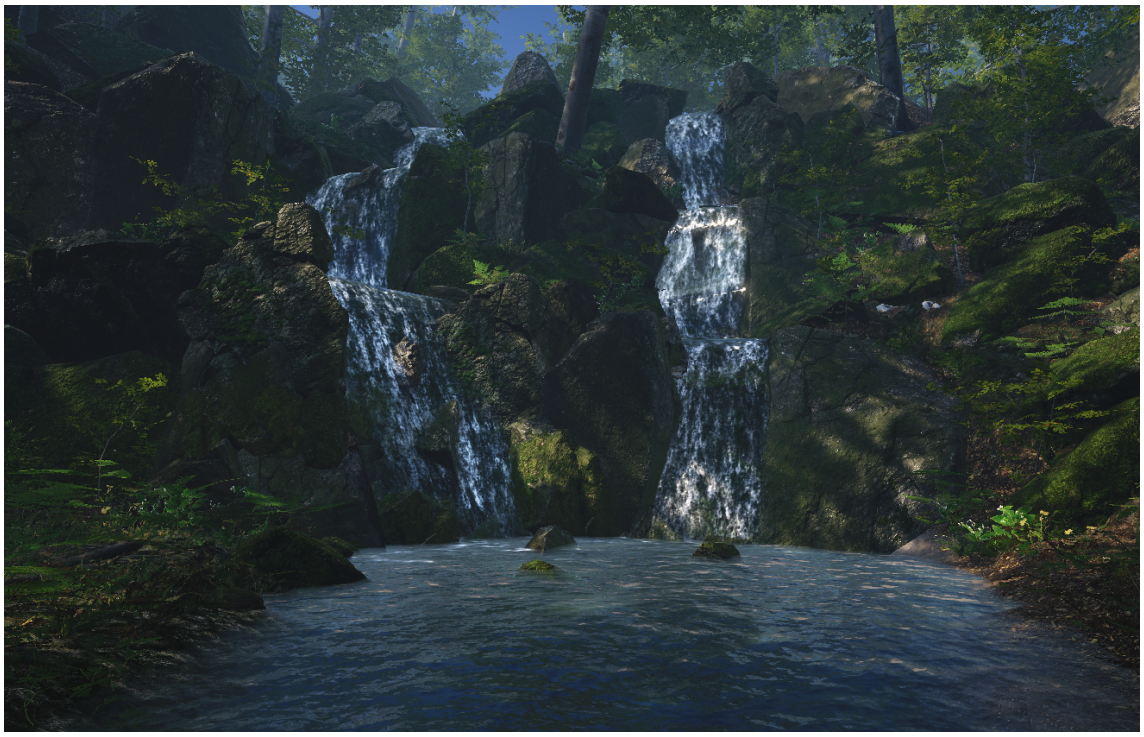


Figure 5.16: Waterfall HD nature

Due to the fact that the environment now is running on a computer with so much higher performance capacity compared to the HMD, focus on the rendering path was not as great as when running the environment as untethered. Firstly it was tested to use the HD render pipeline and trying to tweak that so the environment could run on the HMD. But the HD render pipeline provide low frame updates and a lot of delays in the graphics. Due to what is believed to be that the HMD does not support that kind of quality in graphics, it was decided to run with the Universal render pipeline instead. As stated above, even without tweaking the render pipeline a good result was obtained with a high frame update and no noticeable defections. The following settings was used:

- **Multithreaded Rendering:** Generates intermediate graphics commands by the main thread. The render thread converts them into low-level platform API graphics commands.
- **Static batching:** A draw call batching method that combines meshes that do not move. They are combined so they can be rendered together.
- **Dynamic batching:** A draw call batching method that batches moving objects to reduce draw calls.
- **Multi-View:** The stereo rendering mode will be set to Multiview instead of Multi pass. Multi pass render each eye independently, which requires everything to be done twice. Whit multiview the draw calls are half the amount of multi pass, since it renders both eyes at the same time.

- **Quality: High** The quality is set to High.
- **Anti Aliasing:** 4x Multi sampling
- **Shadows** Will be set to hard shadows only.
- **Lightning** Lightning will be a mix between real time and baked. The lightmap size will be set to 4K

A user test with three users was carried out to obtain knowledge about the design before moving on to the test with the effects of the environment. The test focused on the experience the user had and if they felt like it was close to the real nature. The tests outcome was that it felt realistic to the real nature.

5.6 Questionnaire

The questionnaire was designed to show fifteen images. Three images was of real nature, three of low quality and three of high quality computer generated images of nature and finally three images that could be perceived as stressful. See the full questionnaire in Appendix 2. With each image the participant of the survey have to answer three different statements based on the tension category in the POMS, namely worried, relaxed and uneasy. The statement will read as follows: "This makes me feel relaxed". The answers are based on the Lickert-scale with five different options. The options are the following: Strongly disagree, disagree, undecided, agree, strongly agree. When using Lickert-scale some may argue that it is important to make the participant make a stance, using four question instead of five, leaving out the undecided option. However in this case there is believed that some participants may relate to the images in such a way that they do neither feel more relaxed nor less relaxed. Not providing an answer that resembles this feeling may push the participant to answer in a way that is not coherent with what they feel, resulting in misleading data.

The questionnaire will be distributed through different social medias, such as Facebook, Twitter, Instagram and Linkdin where the questionnaire will also be encouraged to be shared. Communication channels for the master program interaction design on Chalmers will also be used to attract more participants. The participants will be encouraged to answer the questionnaire on a computer because it is believed that seeing the images on a bigger screen may increase the effect of the image.The questionnaire will be available for ten days before the data will be extracted and analyzed. After the ten days of collecting data a total of 76 participants participated in the survey.

5.7 Stress test

Testing the effects of the VR nature environment the participant was first informed about the test. That includes that it is confidential, what is the purpose of the test and that they could quit their participation any time during the test. Thereafter a

POMS-test will be conducted to get a reference of the users mood. The POMS-test will be presented on a A4 paper sheet that the participants will answer anonymously. The POMS-test in the beginning of the test also hopes to prime the participant to notice their mood and how they are feeling. Then the user will put on a pulse monitor to measure their heart rate through out the test. The pulse was then observed so it was not fluctuating to much. Before entering the virtual environment the user was instructed how the application works, such as means of transportation and the layout of the world, to not confuse them when reaching the end of the VR world. Then they put on the HMD and entered the VR nature environment for ten to fifteen minutes and the their heart rate started being recording. The participants then experienced the world on their own terms. After ten to fifteen minutes they will be asked a open question how they feel and then exit the VR. A POMS questionnaire will once again be answered by the participant before an semi-constructed interview takes place. The first POMS and the second POMS will be paired together, still anonymously. The heart rate data that has been recorded will be extracted. After all tests have been executed the data that has been gathered will be analyzed.

The participants of the test is not required to have previous experience with VR. But individuals with earlier experience with VR will be prioritized. This is because it is believed that a first time VR experience may influence the participants in such a way that it may alter the data that are extracted. However if there is not enough individuals with VR experience that participates, individuals without previous VR experience will also be tested. A total of nine user will be part of the testing.

6

Results

This chapter goes over the result that has been produced by the thesis. Firstly the VR environment will be showed and secondly the result from the testing.

6.1 VR World

The final iteration of VR environment was developed for a tethered HMD. The size came to be of roughly 40000 square meters in a square shape, as perceived when carrying the HMD and traveling around in the environment. The whole environment tries to look as much as possible as a forest. The terrain contains slopes and height difference through out the environment. There is many objects in the environment that can be found in a real forest. Such objects as a waterfall, trees, stones, mushrooms, roots, branches and much more. There is some human constructed objects, such as gravel roads and bridges. There is also paths, that could have been created by man or by animals. There is wind blowing through the trees and the rest of the plants in the terrain, which makes the plants sway back and forth. There is fog in the environment, which gives a nice effect with the light and causes the user to perceive the world as bigger, since they can not see as far into the distance. There is different sounds spread out in the environment, such as birdsong, sound from the wind blowing through the leaves of the trees, sound of waterfall and of water running down a calm river. The sounds increases as the user gets closer to the object that causes the sound. Upon turning their head the sound differs from ear to ear, making it possible to determine where the sound is coming from and locate the object that the sound arises from. The end of the environment is covered with plants, such as trees and bushes to prevent the user see over the edge. There is also an invisible wall in between the plants that prevents the user to go in among these trees and getting closer to the edge. More images can be seen in appendix 4

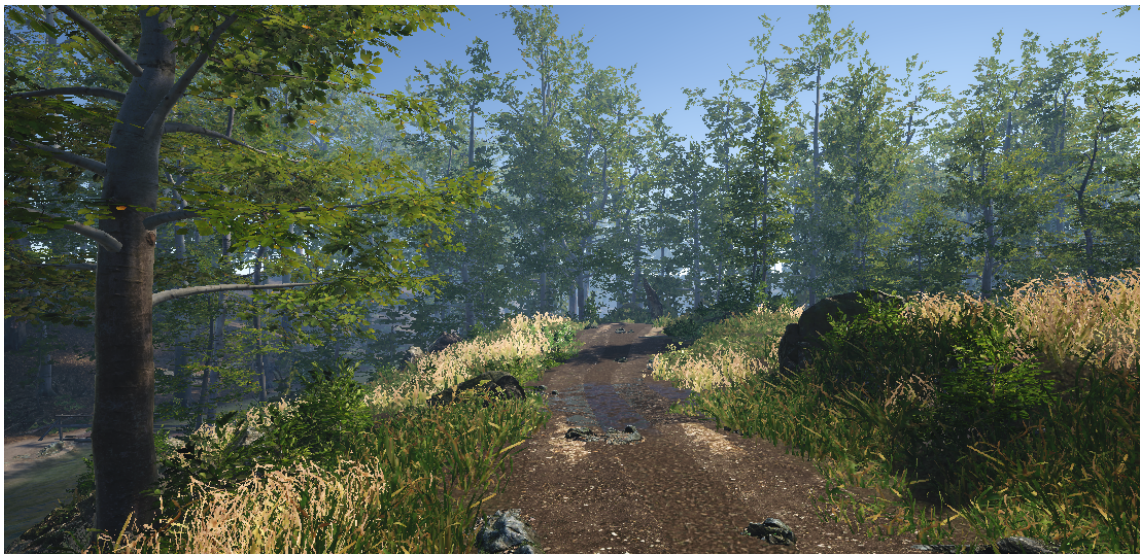


Figure 6.1: Path

Figure 6.2: Waterfall

Figure 6.3: Road in the woods

Figure 6.4: Trees

The user can see two hands that are attached to the controllers, which can be seen in figure 6.5. The user transport themselves by teleportation. This is done by pulling the joystick on the hand controller forward, which causes a ray to appear, upon release of the joystick the user teleport to the end of the ray. However they only teleport to the end of the ray if the ray is green, if it is red upon the release of the joystick they will stay where they are and nothing will happen. The ray can be seen in figure 6.6 and 6.7. It is possible to go all over the environment, but not upon objects other than the ground itself. Such objects as stones is not possible to climb. It is however possible to go in to the water, such as the lake and rivers and look

beneath the surface. As mentioned above there is not possible to go over the edge of the world or close to it.

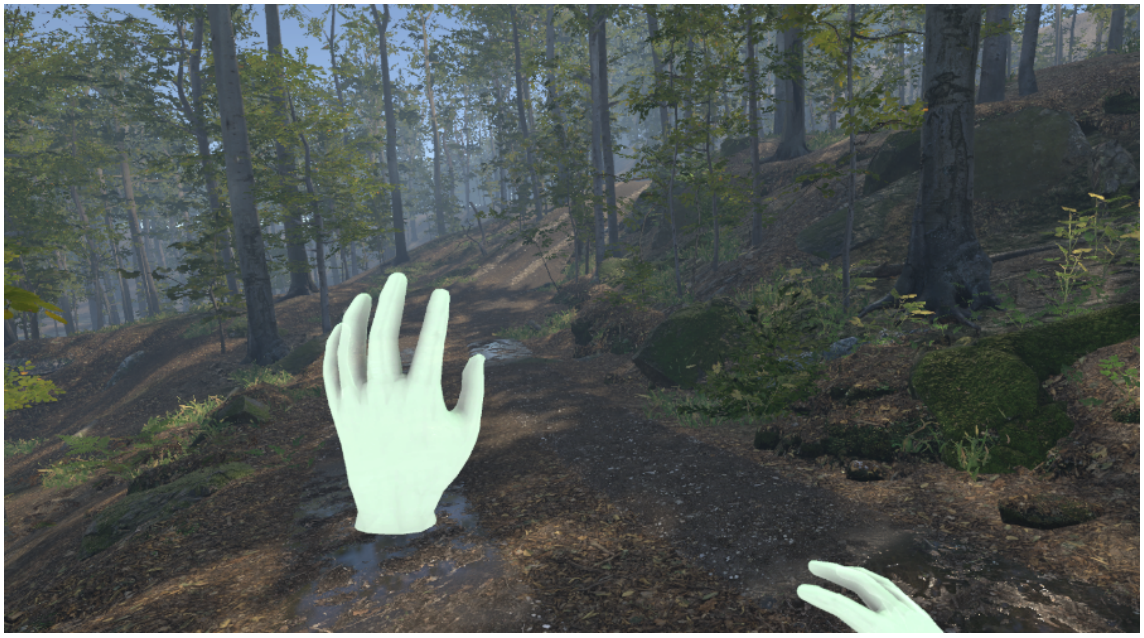


Figure 6.5: Hands

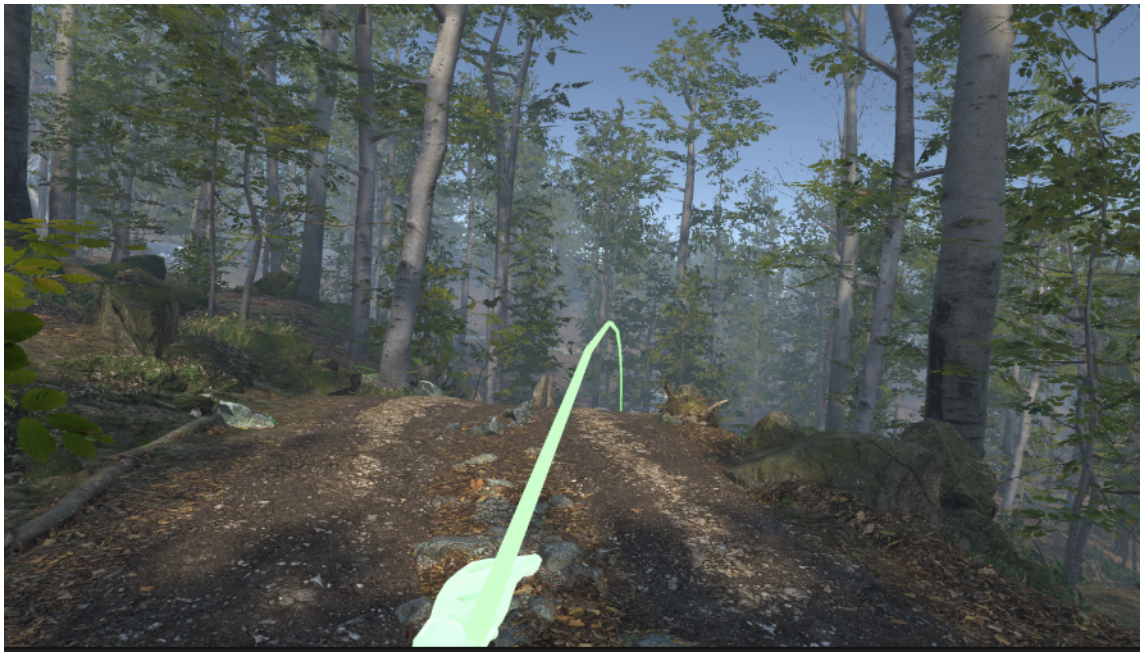


Figure 6.6: Green ray

Figure 6.7: Red Ray

6.2 Questionnaire

For each image type, high definition nature images, low definition nature images, real nature images and stress images, the POMS score was calculated. By adding together all the answers of one image type and then dividing the number with the amount of questions a final answer was received that could be compared between the image types. For example in figure 6.8 the result from the first question in the questionnaire can be seen. The following formula was used to calculate the result for this question. N is the amount of participants, $\%$ is the amount of percent the answer got, and then the number is how much the answer is valued.

$$N * \% * 4 + N * \% * 3 + *\% * 2 + *\% * 1 + *\% * 0$$

The following calculation shows the formula but with the numbers from the first question in the questionnaire.

$$76 * 0.01 * 4 + 76 * 0.04 * 3 + 76 * 0.07 * 2 + 76 * 0.58 * 1 + 76 * 0.30 * 0 = 66.88$$

Keep in mind that the first question asked if the individual felt relaxed, this means that if they strongly agree this scores a 0. The other questions that asks if the individual feel worried or uneasy an answer of strongly agree scores 4.

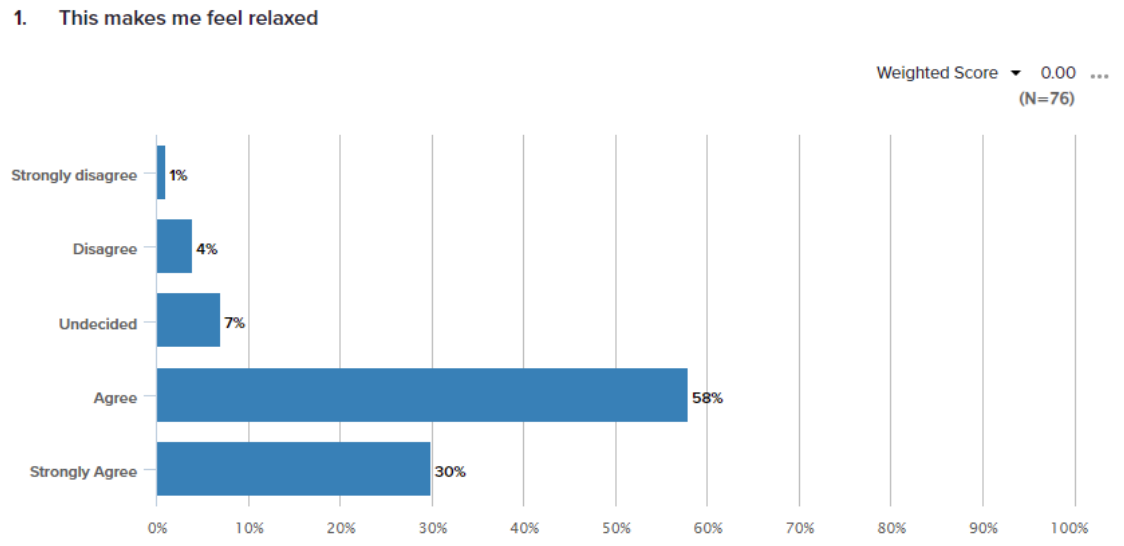


Figure 6.8: Answers Question 1

When all the answers of the question have been gathered and the value of the questions have been calculated they were summed together and then divided on the number of questions. For example the following calculation calculates the value of the high definition images, where the values: 67, 90, 109, 120 and 107 comes from question 1, 2, 6, 10 and 15.

$$(67 + 90 + 109 + 120 + 107)/5 = 98.6$$

Table 6.1 and table 6.2 provides the result from the questionnaire. The table is sorted with the images that provide the least amount of tension for the participants on the top. And then in an descending order the images that causes more and more tension. It can been seen that the real nature images causes the least amount of tension with the participants of the survey. The real nature images are followed by the high definition images and after them the low definition images and finally the images that was supposed to cause tension with the participants.

Type	Total	Average	Percentual increase
Real nature	44	0.58	0 %
High definition	98	1.29	222%
Low definition	167	2.2	379%
Stress	250	3.3	569%

Table 6.1: Overall POMS score questionnaire.

From the survey it is clear that the graphics of the images affects the effect it has on humans. It can also be said that a computer generated image of nature has a more relaxing effect on humans than a image of heavy traffic, messy desk or a messy garage. However even though it was encouraged to do the survey on a computer screen to receive better resolution only 18.4 % of the participants did the survey on a computer screen. The rest did it on a screen with a lower resolution than 428x926, presumably a smartphone. If we look at the result from the 18.4% that answered the questionnaire on a computer screen table 6.2 shows the result.

Type	Total	Average	Percentual increase
Real nature	8	0.57	0%
High definition	20	1.43	251%
Low definition	33	2.36	414%
Stress	45	3.21	563%

Table 6.2: Computer answered POMS score questionnaire.

The result from only answers that came from a computer screen is quite the same as the overall results. The same order in the most relaxing images is the same and the difference between the different types of images. For example the difference in value between real nature images and high definition images for the computer answered survey is a increase of 251 % and for the overall answers between the same types of images is 222 %. The difference between high definition images and low definition images is for the computer answered survey 175% and for the overall answers 169%. Looking at the computer answers and the overall answers it can in be seen that with higher resolution the quality of the graphics makes a bigger impact.

Further to establish the fact that the real nature images was most appealing a few comments from the questionnaire will be shown: "The more it resembles real nature, the more relaxed I personally get", "computer generated nature images are definitely less appealing, they can't transmit the same", "The images with natural green forest light is unchallenged the most relaxing.".

6.3 User test

6.3.1 Heart rate

During the user test the participants heart rate was monitored. In eight out of ten tests the users heart rate slowed down when they entered the nature environment compared to the heart rate before entering the VR. The heart rate then continued to stay on a lower rate throughout the experience. A average experience for the users that the heart rate slowed down is shown in figure 6.9. A bigger heart rate change is shown in figure 6.10. The first value is the value the participants had a few minutes before entering the virtual environment.

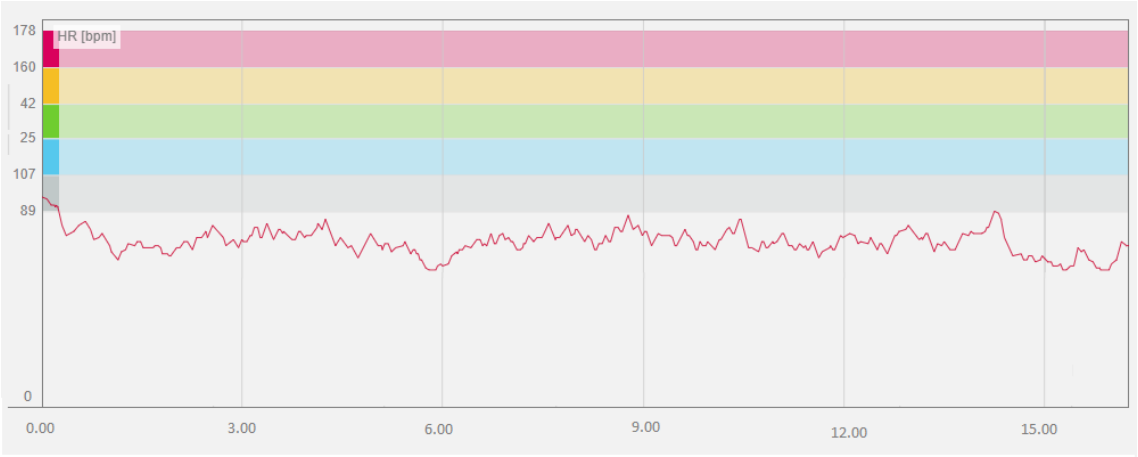


Figure 6.9: Average heart rate

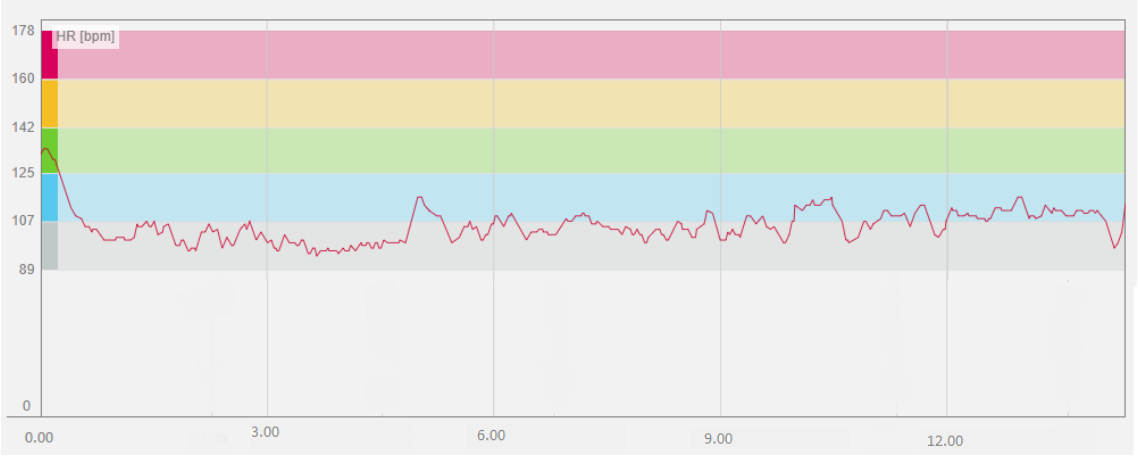


Figure 6.10: Bigger heart rate change

However there where two participants that experienced an opposite effect and instead had an increase in their heart rate. Where the heart rate was around 90 before entering the VR and then it was raised to stay above 107 for the rest of the test. Figure 6.11 shows the graph for a users heart rate with an increase in heart rate rather than a decrease.

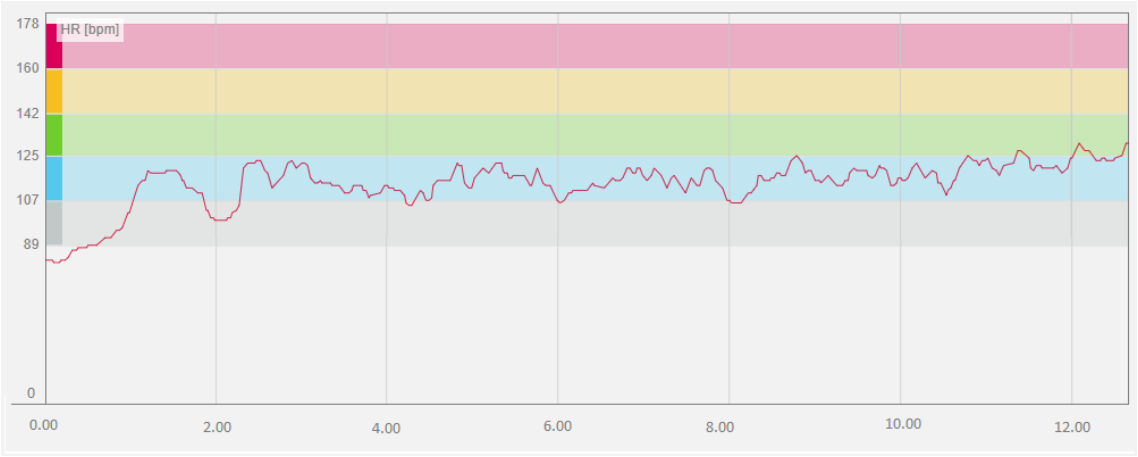


Figure 6.11: Increase in heart rate

For the majority of the individuals that entered the virtual nature environment it had a decreasing effect on the heart rate, but as mentioned there were cases where it had the opposite effect and instead increased.

6.3.2 POMS

The participants of the test answered the same POMS questionnaire before entering the virtual nature environment and after they had spent time in the VR and taken off the HMD. The result of the questionnaires can be seen in the tables below. Table 6.3 shows the overall score from the questionnaire that was taken before the VR experience and after the VR experience. It can be seen that the score after the VR experience is a lot lower than of the score before the VR experience.

Total before	Total after
156	51

Table 6.3: Total POMS score VR test.

Table 6.4 represents each individuals score from the questionnaire before and after. For all participants except one the POMS-score was lower after the VR experience. In one case there was an big difference in the score where it went from 42 to 3, a difference of 39 points. It is hard to find any specific patterns among the results, except that most of the participants got a lower score after the VR experience. In the case where the score increased it is believed that it came from motion sickness, as the participant reported after the VR experience a lack of energy and tiredness. Which also was shown in the the POMS category fatigue where it was a significant increase. A common outcome of motion sickness is a feeling of drowsiness and tiredness [82]. Therefore it is believed that the increase in score was due to motion sickness.

Before	After
22	-3
20	14
14	23
14	3
8	-1
20	7
42	3
4	2
12	3

Table 6.4: Individual POMS score VR test.

Table 6.5 shows the scores of the different mood-categories in the POMS questionnaire. They are divided into the score before and after the VR experience. It can be seen that all the moods have a better outcome after the VR experience. Keep in mind that the mood of vigour, unlike the other moods, is a positive mood and therefore it is positive to have a high score in this mood. All moods was changes in the positive direction for the individual. The biggest impact of the nature experience in VR was in tension that had a difference of 27 points, closely followed by anger that had a difference of 26 points. The lowest impact of the VR nature experience was in the mood of vigour that only had a 3 points difference.

Mood	Before	After	Difference
Anger	31	5	26
Confusion	57	30	17
Depression	15	7	8
Fatigue	80	66	14
Tension	42	15	27
Vigour	76	79	3

Table 6.5: POMS categories score VR test.

6.3.3 Interviews

After the participants had finished their second POMS questionnaire they participated in a semi-constructed interview. The results that came from the interview will be displayed in different themes that came out of the thematic analyze.

- **Feeling:** The common denominator within almost all the answers were that the individual felt relaxed. With the virtual nature experience freshly in mind

words as happy, nice, calm, relaxed and excited were mentioned. The individuals felt free when walking around in the virtual nature environment. They were enjoying the sounds from birds, wind and running water. Some enjoyed the exploration of the world while others stayed closed to the water and felt satisfied there. An appreciation of the wide variety of objects to inspect and take a closer look on, with their high detail caused and excitement. However there was a cases where the user wanted to sit down due to exhaustion in their legs. As well as a scary element when teleporting close to objects, causing a jump scare when for example a tree suddenly appeared right in front of the eyes. Individuals were also inspired to take action when leaving the VR. Such actions were the activities of going out for a walk and to go into nature.

- **Sounds:** The sounds of the virtual nature environment had a big impact according to the participants. It was overall relaxing and realistic. There was specially an appreciation for the running water as well as the bird song. There was however a big difference in the perception of the sounds from individual to individual. Even though all of them thought the sounds were good and of high importance they had experienced it different. Some would have preferred a little less sounds while others would have preferred a little more sounds. The only sound that was local was the one of the water running in different degrees, all other sound were global. But many participants perceived the bird song and the wind as local. For example experiencing the wind picking up when entering open spaces with only grass. Sounds that were local was of high appreciation with the participants.

- **Graphics:** The graphics of the VR was perceived as good and realistic. The details of the objects were impressive, such as moss on the stones and the bark on the trees. The colors of the scene overall were good and realistic, however the sun was a bit to white. Some participants experienced the world as quite shadow rich. The contrast between where the light from the sun reached the ground and where it did not reach were realistic and created depth to the environment. More colors such as flowers with bright colors were wanted. Even though the virtual environment was considered to be realistic there was a common theme of wanting even better graphics.

- **Objects:** The water was a peak for many participants, including the lake, river and waterfall. Otherwise most of the objects in the scene were appreciated, such as the mushrooms, grass, stones, logs, bridges, path etc. Not a single object got a bad comment, however the origin of the waterfall was mentioned. The start of the waterfall is hidden beneath rocks but it was obvious that the waterfall appeared from "nowhere". The participants wanted to see some additional objects. Adding of animals was empathized by most participants, such as rabbits, fishes, birds, butterflies, insects etc. As well as adding of more colorful flowers

- **Teleportation:** The means of transport through teleportation was well received. However the fact that when teleporting close to an object it may

appear right in front of the eyes and cause fright with the individual, this was not perceived as good. Furthermore it would have been appreciated if there was also possibly to move around through continuous movement.

- **Hands:** The hands that were connected to the controllers did not take much notice of the participants. The ones that did pay closer attention to them would have them more realistic and it was a bit scary that it was possible to move the hands through objects, such as trees. They were also static, and the participants would had appreciated some function to move the hands, such as a pinching motion to be able to grab things. Hand tracking without controllers as well as feet tracking were suggested to increase the feeling of immersion.

- **Immersion:** There were a high level of immersion were most participants felt as they were in the real nature. Comments such as "I forgot about the outside world" were mentioned. However there were some factors that broke the immersion such as, the means of teleportation, the hands, walking out side of the guardian-system, light slipping through the HMD, sounds from outside the VR.

- **Environment:** A few participants tried to reach the edge of the VR world, to see where it ended but quite quickly gave up before they reached the wall or before due to a believe that the world was too big. The fact that it was able to go beneath the surface of the water as well as standing in the waterfall was appealing to the participants. Not a single participant tried to exploit the system in any kind of way(except trying to reach the end of the world).

  Participants suggested that adding of a viewpoint that could create an understanding of the environment as well as more open areas would be beneficial. Another additional feature that was viewed as beneficial by the participants was collecting of mushrooms and/or be able to interact with the environment in some way.

As can be seen in the result from the thematic analyze of the interviews above there was a positive response from the participants. Most of the participants could have stayed longer in the environment when their time came to an end. They felt calmer after the experience and could have returned to the environment another time. Even if there is room for further development of the environment it is clear that the participants of the test had a positive experience from spending 10-15 minutes in the virtual nature environment.

7

Discussion

7.1 Results

The results of this master thesis can be divided in to two parts. Firstly the designing and development of the VR environment and secondly the testing of the effects of a nature experience in a VR environment.

7.1.1 VR environment

The VR environment that was created came to be of a fairly realistic nature and close to the real nature. It still have some setbacks such as a invisible wall when getting close to the edge. But all in all it came to become a good virtual nature environment that exceeded the writer for he thesis expectations. Especially in the level of detail the scene provides, such as the wind swaying the trees and the grass and how the water reflects the sun that shines through the tree canopy.

The goal in the beginning was to create a application for a untethered HMD. But due to its limitations it was decided to use a tethered HMD instead. This provides a much higher performance capability from the hardware allowing for a more realistic experience. Even though that this might have lowered the feeling of immersion as there is a cable running from the headset, clearly noticeable for the user, in to the computer the positive effects of a tethered HMD seemed to overweight the negative. Enough knowledge were not obtained before the project regarding the capacity of the hardware on a Oculus Quest 2. The aim was to create a realistic experience, which seemed achievable until the development of the application started, and foremost the test running on the untethered device. After optimizations in the render pipeline was conducted it seemed clear that the desired quality of the application did not meet the result that was achieved. As seen in the questionnaire regarding the effects of different nature images the graphic made a significant difference. Therefore a move to a tethered HMD was justified. As the hardware keep evolving this might change in the future.

The graphics of the scene was well received with the individuals that tested the environment. They thought it looked realistic and provided a great level of detail through out the scene. However there were still wishes for better graphics to make it even more realistic and immersive. As mentioned in the process section there

were some test with the HD render pipeline that did not provide a desired result. Believed to be due to limitation with the hardware in the HMD, for most the display. Instead the universal pipeline was used with some optimization. Due to the fact that the application was running smoothly on the HMD there was not a great amount of time put ion to the optimization of the render pipeline. As mentioned earlier the rendering of an application is a complicated topic that requires a great deal of research, implementation and testing to achieve a desired goal. The goal in this case would be as good graphics as possibly with a frame rate per second of 72. Due to the time limit of the thesis and due to the fact that a desirable graphic quality with a fps of 72 was obtained, no further work was done on the render pipeline.

7.1.2 Testing

Starting working on the thesis the goal was to get some indications on what degree a nature experience in a virtual environment can have on the individual. The results that came about after the testing shows clearly that it does have a positive effect on the well-being of the individual. Eight out of nine had a positive experience and felt like they left the virtual nature world in a better mood. This is also supported from the POMS question the participants had to answer before and after the test, where it is shown a significant difference in the score from before and after the experience. Further it is also shown in the heart rate of the participants, where seven out of nine had a decrease in heart rate. This points towards that there is a relaxing effect after having taking a VR nature pill. However it must be made clear that there is only nine individuals that has been tested and there is not enough data to show that this could imply on all individuals. But there is certainly possible for a nature experience within VR to have a positive effect on the well-being of the individual, and in some cases a big impact on their well-being.

When testing the difference in mood with individuals they may have come with a lot of bias. Depending on their current life situation they may be more accessible to have a positive change in their mood. Some participants may have been in a stressful state just before, like writing an exam or trying to finish some other task. While others may come from a relaxful state, such as day off with a pleasant morning or a workout that made them calm. These factors may influence the outcome of the test in terms of how the participants react and respond to the VR experience, which will then be shown in the data that was gathered. However in this study what the participants life situation was when taking the test was not looked into due to privacy reasons. It is still important to have in mind that there are outer factors that may have alter the result of the study to a high degree. Other factors may be such as the participants manufactures their answers to please someone. This someone could be the writer of the thesis, which the participants may think that a positive effect will help the writer of the master thesis. Or it can be themselves and think that they must become calmer after the experience. It can also be due to mental-models, such as a belief that nature should have a calming effect on the mind and body. Still all the data that has been gathered points towards a calming effect on the individual during and after a nature experience in VR.

When testing the effects of an experience within the virtual nature environment it was decided that the participants will be in the environment for about ten to fifteen minutes. Even though research have shown that the optimal time spent in nature to get a maximum effect is twenty minutes. However after twenty minutes the effects starts to decrease, meaning that the individual will get the maximum effect to time ratio up to twenty minutes. After twenty minutes there will still be a positive effect from nature but the impact will slowly decrease. Choosing ten to fifteen minutes was because a few reasons. Firstly, twenty minutes within VR with out taking of the HMD could be too much for some people, leaving them with sore eyes, headache, motion sickness etc. It was also believed that the individual might get bored of just going around in the nature for twenty minutes. Not knowing the previous experience of the participant they might be used to constant stimulation and the nature environment imposes the possibility of less obvious stimulation, which might could cause boredom with the individual. Ten to fifteen minutes should still be enough to get a positive effect out of the experience, which was shown in the results.

Testing the effects of the nature experience in the virtual environment had to use some sort of metrics. The first one chosen was the subjective feeling of the individuals. With more than ten tests this was seen as providing a rather correct picture of the outcome of the virtual nature experience. However additional metrics in form of more concrete type was desired. Firstly the idea was to measure the cholesterol value in the body during the test. This provides an accurate measurement of the stress levels in the body as the cholesterol value is directly related to stress. Unfortunately measuring the cholesterol levels was not plausible as the only option available was to buy test from the commercial sector. This test are fairly expensive, and to have a correct picture of the stress level a total of three tests would have been executed. One test before the stress inducer, one test before entering the virtual nature environment and one test after. Instead of using the cholesterol value in the body it was decided to use the pulse as a concrete data. Even though, as mentioned in the background, the pulse seems to be co related to the stress levels but its not certain it has a direct connection for all individuals. It still seemed like the data obtained from the pulse measurements would provide useful insight about the effects of a virtual nature experience. Therefore it was decided to apply pulse measurements in the testing of the effects of the VR nature experience. Is it then possible to draw any conclusion from the heart rate monitoring? I do believe it gives a hinge on what is possible. As seen 80% of the individuals that entered the virtual nature environment had a decrease in their heart rate. 80 % is a fairly high number that indicates that the virtual nature environment have a decreasing effect on the heart rate.

There was also an observation of the users breathing. But no remarkable changes in the breathing was noticed and therefore it was not part of the result. Extracting data on the breathing only by observation through the eye was a bit optimistic in the aftermath.

7.2 Process

The process of the master thesis has been quite straight forward. Where it all started with research, then planning, developing, testing and analyzing. The research phase went on smoothly. The main focus for the research where how nature influences the human body and in similar research area as this thesis. Obtaining knowledge about unity was also conducted, where a course in C# Unity Game Developing in 3D [83] was taken.

The planning did not hold to the end of the project. The main reason for this was that the developing of the virtual environment took longer than expected. This was due to a lack of knowledge about unity and 3D programming. This knowledge was instead picked up as the project went on and the developing of the VR environment made progress. This caused a delay with a month from the original time schedule.

Developing the VR environment came with some difficulties. The big reason being that for every step taken information about how to implement and code the step had to be obtained. Which took longer time than expected. The course C# Unity Game Developing in 3D helped a lot but was not sufficient. This in the after math should have been expected because it is quite common that the programming and developing may take longer time than one may think in the beginning. Especially since there was no previous experience in developing for VR. However many things were learned and a good application was created in the end.

Testing the application to see what kind of effects it had on the individual went smoothly. The planning of the testing was a bit tricky because testing a subjective feeling for many individuals and then be able to draw conclusion of the results was not straight forward. But in the end there was a variety of data that was obtained from the testing that lead to a clear result. Analyzing the data was as well a bit uncertain beforehand, especially the data that would come out of the POMS questions. But in the end it seemed trivial what to do with the data.

All in all the master thesis have been a good experience that have constantly taking small steps forward. Dividing the work in to different sections such as sprints helps the progress as it is clear on what one should work with. It also helps with moving forward as there is a deadline where the work that has been done will have to be sufficient. If not sprints had been used there would have been a possibility to stay with one part for to long. As there is constantly a feeling of wanting to do more, either if it is about doing more research or polishing the VR environment.

7.3 Generalizability

To make a statement that this master thesis has come to a conclusion that can be drawn over all humans is not possible. This is due to the fact that there need to be a bigger and more extensive research with foremost more individuals that is being tested. So to generalize the result is not believed to be possible.

7.4 Ethical aspects

During this master thesis it was crucial to collect data from user and to execute user tests. To conduct user tests and gather the data users had to be a part of the process. It was important to make the users that participated to feel safe and comfortable as well as feeling informed. The part of sharing information with the participants contained a little bit of struggle, since it was believed that if too much information about the project was shared before conducting the gathering of the data (which includes user tests) it may affect the participants in such a way that it would alter the data. For example if the studies done on the benefits of exposing an individual to nature had been told to the participants before the test they may take this information with them and alter the answers based on the knowledge that nature "should" have a positive effect. Instead such information was shared with the participants after the gathering of the data had finished.

It was also tricky to oversee the participants while in the VR. VR may cause motion sickness with users and it was clearly instructed before conducting the test that motion sickness may occur, and if it does there is no problem to end the test or take a break. To end the test or take a break was available even without the feeling of motion sickness, which was clearly instructed with the participants.

The application that was designed and developed tried to include as many users as possible. If the user have experience within VR from before or not should not matter if they want to use the application. If the user has a physical limitation it is still possible to use the application. One could sit down and still move around and enjoy the environment, either using the right or left hand.

All data that was gathered was confidential. To keep track of the different tests and participants for analyzing random numbers were used. The interviews that were recorded was deleted after the data from them was extracted. Except for the interviews all the data was recorded with pen and paper, only being inputted in the computer once the data was organized and compiled. Nothing that can tie the participants to the data that is shown is left behind.

7.5 Further work

Further development of the application can be done in several ways. The following will suggest such improvements to the application. Creating a bigger environment for the user to travel around in, mostly for user that intend to use the application several times might need a bigger environment to explore. This can also be achieved through creating a whole new scene that the users can reach in some way, perhaps through some kind of teleport in the current environment. Implement hand tracking that does not require the controllers to be held by the user, instead traversing in the environment through hand gestures for further immersion. Implement continuous walking in such a way that it is realistic towards real physics, for example not possible to walk up steep slopes.

Implement animals of different kinds, for example smaller mammals, such as rabbits or squirrels, maybe even bigger animals, such as deer and elks. Birds, sitting on a branch or flying in the air. Insects, such as butterflies, ant stacks and beetles. Fishes, salmons jumping in the waterfall or schools of fish swimming in the lake.

Implement more local sounds, such as bird song preferably connect to the object of a bird, flying or sitting still. If continuous movement is implemented, match the sounds when walking to the ground. If the user is walking on branches, on sand or through water it should make different sounds.

Implementation of an activity can also be done. Such as fishing or climbing somewhere in the environment. Even though this may not help determine the effects a nature experience has on a human it may contribute to an application that has a positive effect on individuals.

The testing of the effects of an virtual nature experience can be extended. Firstly it can be done with more participants to get a more reliable result. It can also be extended by having the participants experience a real nature environment. Having the participants doing the exact same test as with the VR nature but with real nature instead of VR nature will provide a baseline and something to compare the scores and outcome of the test. Testing the cortisol of the participants before and after the test can lead to more concrete and reliable data. Right now there is only the heart rate that provides concrete data that is not subjective and controlled by the participant. Testing the cortisol can provide more information on what is happening in the body after a nature experience, since it is has a more reliable connection to the stress levels of the body compared to the heart rate. All this suggestions will lead to a better understanding of the benefits of a VR nature experience.

Optimize the render pipeline can be done in a greater length. As mentioned in the thesis the rendering of graphics is complicated and much time can be invested to get a good render pipeline. Even though it is believed that the graphics will not change that much due to configuration of the render pipeline there is definitely possibility for further work within this area.

8

Conclusion

This project has tried to obtain knowledge regarding the effects a nature experience in a virtual reality environment can have on the individual, more specific the individuals mental-state being. Even though it is hard to make any big conclusion based on the low number of participants that participated in the project. The project is as mentioned in the beginning of the report a exploratory research, trying to give an indication of the effects of a VR experience in a nature environment. Based on the results that came out of the testing there can be said that there is strong indications that a computer generated nature environment will have beneficial effects on an individuals well-being. Further to have the individual experience a VR nature environment with a HMD seems to have positive effects on eight out of nine participants. Participants that did not suffer from motion-sickness felt less anger, depression, confusion, fatigue and tension. It was also common to have an urge to move the body afterwards, such as walk and especially a walk in a nature environment.

The research question that have been sought out to be answered was the following: "Can a virtual nature experience have beneficial effects on the user?". The conclusions towards that questions is that a virtual nature experience had a positive effect on the individual well-being. However as mentioned before it is a low amount of participants in the study and it has to be taken in consideration that the data is not of a high quantity. The main factor that held the immersion for the individuals back was the graphic. It can then be believed that with further development of the technology within VR, the effects of an experience within a virtual nature environment will get more beneficial. To answer the secondary question “Do the quality of the graphics of the nature make any difference for the user?”, yes it clearly does. Based on the interviews from the user test where the graphics were a big factor for the users and the results from the questionnaire which clearly shows that the quality of the graphics do matter. Computer generated images of nature compared to real nature images does not reach the same level of pleasing. Even though the computer generated images is still pleasing to the human eye.

It is however important to have in consideration that it is not clear what causes the positive effect on the individuals well-being. It may be the sound, graphics, disconnection from the world or the mental-model of the individual. Perhaps there is a combination of all the elements just mentioned together that causes the positive

impact. To sum up the conclusion: It is possible for a virtual nature experience to have a positive effect on the user. Even though more data is required to draw bigger conclusions.

Bibliography

[1] Mark Billinghurst. (2021) COMP 4010: Virtual Reality, Introduction to VR. https://docs.google.com/document/d/1sqsGCHC5HexMOBbBV4wIuGUQx8ypU4td_-oH7ghoLFI/edit

[2] Alsop, T. (2021-07-19). Virtual reality (VR) headset unit sales worldwide from 2019 to 2024. Retrieved 10, 2021, from https://www.statista.com/statistics/677096/vr-headsets-worldwide/

[3] Alsop, T. (2021-03-17). Consumer and enterprise VR market size worldwide 2019-2024. Retrieved 10, 2021, from https://www.statista.com/statistics/1221522/virtual-reality-market-size-worldwide/

[4] The World Bank (2018). Urban population (% of total population) - Sweden. Retrieved 10, 2021, from https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=SE

[5] Roger S. Ulrich, Robert F. Simons, Barbara D. Losito, Evelyn Fiorito, Mark A. Miles, Michael Zelson, Stress recovery during exposure to natural and urban environments, Journal of Environmental Psychology, Volume 11, Issue 3, 1991, Pages 201-230, ISSN 0272-4944, https://doi.org/10.1016/S0272-4944(05)80184-7.

[6] Mental health statistics: stress.(2018). Retrieved 09,2021 from https://www.mentalhealth.org.uk/statistics/mental-health-statistics-stress.

[7] World Stress Index.(2021) Retrieved 10,2021 from https://worldstressindex.com/

[8] Haluza, D., Schonbauer, R., and Cervinka, R. (2014). Green perspectives for public health: a narrative review on the physiological effects of experiencing outdoor nature. Int. J. Environ. Res. Public Health 11, 5445–5461. doi: 10.3390/ijerph110505445

[9] Hartig, T., van den Berg, A. E., Hagerhall, C. M., Tomalak, M., Bauer, N., Hansmann, R., et al. (2011). Health Benefits of Nature Experience: Psychological, Social and Cultural Processes. New York, NY: Springer.

[10] Bratman, G. N., Hamilton, J. P., and Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. Ann. N. Y. Acad. Sci. 1249, 118–136. doi: 10.1111/j.1749-6632.2011.06400.x

[11] Hansen, M. M., Jones, R., and Tocchini, K. (2017). Shinrin-Yoku (Forest Bathing) and nature therapy: a state-of-the-art review. Int. J. Environ. Res. Public Health 14:48. doi: 10.3390/ijerph14080851

[12] Hartig, T., Mitchell, R., de Vries, S., and Frumkin, H. (2014). Nature and health. Annu. Rev. Public Health 35, 207–228. doi: 10.1146/annurev-publhealth-032013-182443

[13] Logan, A. C., and Selhub, E. M. (2012). Vis Medicatrix naturae: Does nature "minister to the mind"? Biopsychosoc. Med. 6: 11. doi: 10.1186/1751-0759-6-11

[14] Berman, M. G., Jonides, J., and Kaplan, S. (2008). The cognitive benefits of interacting with nature. Psychol. Sci. 19, 1207–1212. doi: 10.1111/j.1467-9280.2008.02225.x

[15] Louv, R. (2010) Last Child in the Woods. Atlantic Books.5

[16] Lois A. Wessel, Shifting Gears: Engaging Nurse Practitioners in Prescribing Time Outdoors, The Journal for Nurse Practitioners, Volume 13, Issue 1, 2017, Pages 89-96, ISSN 1555-4155, https://doi.org/10.1016/j.nurpra.2016.06.013.

[17] James AK, Hess P, Perkins ME, Taveras EM, Scirica CS. Prescribing Outdoor Play: Outdoors Rx. Clinical Pediatrics. 2017;56(6):519-524. doi:10.1177/0009922816677805

[18] The Biophilia Hypothesis, Stephen R. Kellert and Edward O. Wilson. 1993. Island Press, Washington, DC. Bulletin of Science, Technology & Society. 1995;15(1):52-53. doi:10.1177/027046769501500125

[19] Kaplan, R., Kaplan, S., 1989. The Experience of Nature: A Psychological Perspective. Cambridge University Press, Cambridge

[20] . Fowler D. 2002. Pollutant deposition and uptake by vegetation. In Air Pollution and Plant Life, ed. JNB Bell, M Treshow, pp. 43–67. New York: Wiley. 2nd ed.

[21] Bize R, Johnson JA, Plotnikoff RC. 2007. Physical activity level and health-related quality of life in the general adult population: a systematic review. Prev. Med. 45:401–15

[22] Cacioppo Stephanie, Cacioppo John, 2012, Decoding the invisible forces of social connections, Frontiers in Integrative Neuroscience volume 6, doi:10.3389/fnint.2012.00051

[23] Ulrich, R.S. 1983. Aesthetic and affective response to natural environment.

Hum. Behav. Environ. Adv. Theor. Res. 6:85–125.

[24] Hartig, T., G. Evans, L. Jamner,et al. 2003. Tracking restoration in natural and urban field settings. J. Environ. Psychol 23: 109–123.

[25] Kaplan, R. & S. Kaplan. 1989. The Experience of Nature: A Psychological Perspective. Manuscript, University of Nevada,Reno. Cambridge University Press. Cambridge.

[26] James, W. 1892. Psychology: The Briefer Course. Holt. New York.

[27] Ulrich RS: Visual landscapes & psychological well being. Landscape Res. 1979, 4: 17-19.

[28] Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M: Stress recovery during exposure to natural and urban environments. J Environ Psychol. 1991, 11: 201-230. 10.1016/S0272-4944(05)80184-7.

[29] Chang CY, Hammitt WE, Chen PK, Machnik L, Su WC: Psychophysiological responses and restorative values of natural environments in Taiwan. Landscape Urban Plan. 2008, 85: 79-84. 10.1016/j.landurbplan.2007.09.010.

[30] Chang CY, Lin YH, Chou MT: Experiences and stress reduction of viewing natural environmental settings. Acta Hortic. 2008, 775: 139-146.

[31] Alvarsson JJ, Wiens S, Nilsson ME. Stress Recovery during Exposure to Nature Sound and Environmental Noise. International Journal of Environmental Research and Public Health. 2010; 7(3):1036-1046. https://doi.org/10.3390/ijerph7031036

[32] Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Lawler, J. J., et al. (2017). Nature contact and human health: a research agenda. Environ. Health Perspect. 125:075001. doi: 10.1289/ehp1663

[33] Shanahan, D. F., Bush, R., Gaston, K. J., Lin, B. B., Dean, J., Barbe, E., et al. (2016). Health benefits from nature experiences depend on dose. Sci. Rep. 6:28551. doi: 10.1038/srep28551

[34] Hunter MR, Gillespie BW and Chen SY-P (2019) Urban Nature Experiences Reduce Stress in the Context of Daily Life Based on Salivary Biomarkers. Front. Psychol. 10:722. doi: 10.3389/fpsyg.2019.00722

[35] Thomson JA: The popular lecture: vis medicatrix naturae. BMJ. 1914, 2: 277-279. 10.1136/bmj.2.2797.277.

[36] IT News. (2016-05-06) VR-Virtual Reality. Retrieved 2021-11-02 from https://itnewsreporter.blogspot.com/2016/05/vr-virtual-reality.html

[37] VRINFLUX. (2015-11-08). Vergence-accommodation conflict is a bitch — here's how to design around it. Retrieved 2021-11-02 from https://medium.com/vrinflux-dot-com/vergence-accommodation-conflict-

is-a-bitch-here-s-how-to-design-around-it-87dab1a7d9ba

[38] Virtual Speech. (2019-05-19). Degrees of Freedom (DoF): 3-DoF vs 6-DoF for VR Headset Selection Retrieved 2021-10-25 from https://virtualspeech.com/blog/degrees-of-freedom-vr

[39] Strasburger H. Seven Myths on Crowding and Peripheral Vision. i-Perception. May 2020. doi:10.1177/2041669520913052

[40] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley.

[41] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley. Chapter 2

[42] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley. Chapter 3

[43] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley. Chapter 5

[44] Jones, J. (1970) Design Methods: Seeds of human futures. Wiley-Interscience

[45] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley. Chapter 6

[46] GOULD, J. D., AND LEWIS, C. H. (1985) Designing for usability: key principles and what designers think. Communications of the ACM, 28(3), 300-311.

[47] Preece, J., Rogers, Y. & Sharp, H. (2019). Interaction design : beyond human-computer interaction. Indianapolis, IN: Wiley. Chapter 7

[48] Taylor, Andrew. (2000). IT projects: Sink or swim. The Computer Bulletin. 42. 10.1093/combul/42.1.24.

[49] SCHBN, D. (1983) The Reflective Practitioner: How Professionals Think in Action. New York: Basic Books.

[50] Steven Vi, Tiago Silva da Silva, and Frank Maurer. (2019). User Experience Guidelines for Designing HMD Extended Reality Applications. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-29390-1_18

[51] LeBlanc, M., ed. 2004a. Game Design and Tuning Workshop Materialsî, Game Developers Conference 2004. Retrieved 11,2021 from http://algorithmancy.8kindsoffun.com/GDC2004/

[52] Hunicke, R; LeBlanc, M; & Zubek, R. MDA: A Formal Approach to Game Design and Game Research. CiteSeerX: 10.1.1.79.4561

[53] Wadsworth, Yoland. (2011). Do It Yourself Social Research. 10.4324/9781003115373.

[54] W. C. Booth, G. G. Colomb, J. M. Williams, J. Bizup, and W. T. Fitzgerald,The Craft of Research. Chicago: University of Chicago Press, 2016.

[55] Nielsen Norman Group, Why You Only Need to Test with 5 Users, retrieved 11. 2021 from https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

[56] W. Gaver, "What should we expect from research through design?," inProceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI'12, (New York, NY, USA), p. 937–946, Association for Computing Machinery,2012.

[57] Google, Design sprints. retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/overview

[58] Google, How Might We, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase1-understand/hmw-sharing-and-affinity-mapping

[59] Google, The Golden Path, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase2-define/golden-path

[60] Google, Success, Metrics and Signals, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase2-define/success-metrics-signals

[61] Google, The Warm Up: Comparable Problem, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase3-sketch/warm-comparable-problem

[62] Google, Crazy 8's, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase3-sketch/crazy-8s

[63] Google, Solution sketch, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase3-sketch/solution-sketch

[64] Google, Decide, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase4-decide

[65] Google, Decision Matrix, retrieved 11, 2021 from https://designsprintkit.withgoogle.com/methodology/phase4-decide/decision-matrix

[66] Unity, Unity, retrieved 11, 2021 from https://unity.com

[67] Unity, Welcome to Unity, retrieved 11, 2021 from https://unity.com/our-company

[68] Unreal Engine, Unreal Engine, retrieved 11, 2021 https://www.unrealengine.com/en-US/

[69] Wadsworth, Yoland. (2011). Do It Yourself Social Research. P. 67-75 10.4324/9781003115373.

[70] Trello, Trello, retrieved 11,2021 from https://trello.com/

[71] Taelman J., Vandeput S., Spaepen A., Van Huffel S. (2009) Influence of Mental Stress on Heart Rate and Heart Rate Variability. In: Vander Sloten J., Verdonck P., Nyssen M., Haueisen J. (eds) 4th European Conference of the International Federation for Medical and Biological Engineering. IFMBE Proceedings, vol 22. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-89208-3_324

[72] Oculus for developers, Art Direction for All-in-One VR Performance, retrieved 12, 2021 from https://developer.oculus.com/documentation/native/android/po-art-direction/

[73] Unity asset store, Standard Assets (for Unity 2018.4), retrieved 12, 2021 from https://assetstore.unity.com/packages/essentials/asset-packs/standard-assets-for-unity-2018-4-32351#description

[74] Unity Documenation, Terrain, retrieved 12, 2021 from https://docs.unity3d.com/Manual/script-Terrain.html

[75] Unity Learn, Unit 8 - Performance Requirements, retrieved 12, 2021 from https://learn.unity.com/tutorial/unit-8-performance-requirements?uv=2018.4&courseId=5d955b5dedbc2a319caab9a0#

[76] Oculus for Developers, Monitor Performance with OVR Metrics Tool retrieved 01, 2022 from https://developer.oculus.com/documentation/unity/ts-ovrmetricstool/

[77] Unity asset store, Forest Environment - Dynamic Nature, retrieved 01, 20222 from https://assetstore.unity.com/packages/3d/vegetation/forest-environment-dynamic-nature-150668

[78] Unity asset store, Nature - Essentials, retrieved 01, 2022 from https://assetstore.unity.com/packages/audio/ambient/nature/nature-essentials-208227

[79] McNair, D. M., Lorr, M., & Droppleman, L. F. (1971). Manual for the Profile of Mood States. San Diego, CA:Educational and Industrial Testing Services.

[80] Petrowski Katja, Albani Cornelia, Zenger Markus, Brähler Elmar, Schmalbach Bjarne. Revised Short Screening Version of the Profile of Mood States (POMS) From the German General Population, Frontiers in Psychology, Volume 12, 2021. DOI=10.3389/fpsyg.2021.631668

[81] Polar, POLAR VERITY SENSE, retrieved 02, 2022 from https://www.polar.com/ie-en/products/accessories/polar-verity-sense

[82] Lawson BD, Mead AM. The sopite syndrome revisited: drowsiness and mood changes during real or apparent motion. Acta Astronaut. 1998 Aug-Sep;43(3-6):181-92. doi: 10.1016/s0094-5765(98)00153-2. PMID: 11541923.

[83] Udemy, Complete C# Unity Game Developer 3D, retrieved 03, 2022 from https://www.udemy.com/course/unitycourse2/

A

Appendix 1

A.1 Questionnaire Lo-Fi

- Which of the following indicates your experience with VR? 1: I don't have any experience. 2: I have a little experience. 3: I am an expert.
- How would you describe your overall experience with the product?
- What did you like the most about using this product?
- What did you like the least?
- What do you like about this virtual world?
- What do you like the least about this virtual world?
- How would you improve this idea/product?
- How appealing are the following features: The lake? ocean? mountains? path?
- How well do the following statements describe the product? Relaxing.
- Would you like to add anything else?

A.2 Questionnaire Lo-Fi 2

- Which of the following indicates your experience with VR? 1: I don't have any experience. 2: I have a little experience. 3: I am an expert.
- How often do you spend time in nature? 1: Never 2: Very Rarely (once per month) 3: Rarely (2-3 times/month) 4: Occasionally (2-3 times/week) 5:Frequently (1-2 times/day) 6: Very Frequently (3+ times/day)
- How would you describe your overall experience with the product?
- What did you like the most about using this product?
- What did you like the least?

- What do you like about this virtual world?
- What do you like the least about this virtual world?
- How would you improve this idea/product?
- How appealing are the following features: The lake? ocean? mountains? path?
- How well do the following statements describe the product? Relaxing.
- How frequently would you use this product? 1: Never 2: Very Rarely (once per month) 3: Rarely (2-3 times/month) 4: Occasionally (2-3 times/week) 5:Frequently (1-2 times/day) 6: Very Frequently (3+ times/day)
- Would you like to add anything else?

B

Appendix 2

The survey will take approximately 5 minutes to complete. All answers are anonymous. The survey is a part of a master thesis project at Chalmers university of technology researching the effects a nature environment experience within virtual reality have on humans.

You will now see fourteen images. Take a moment to feel what the image tells you and then answer how well the statement below the image match your sensations. It is recommended to do the survey on a computer as the images will be bigger, but smartphone is also possible.

Thank you for your participation.

Figure B.1: Introduction

1. This makes me feel relaxed

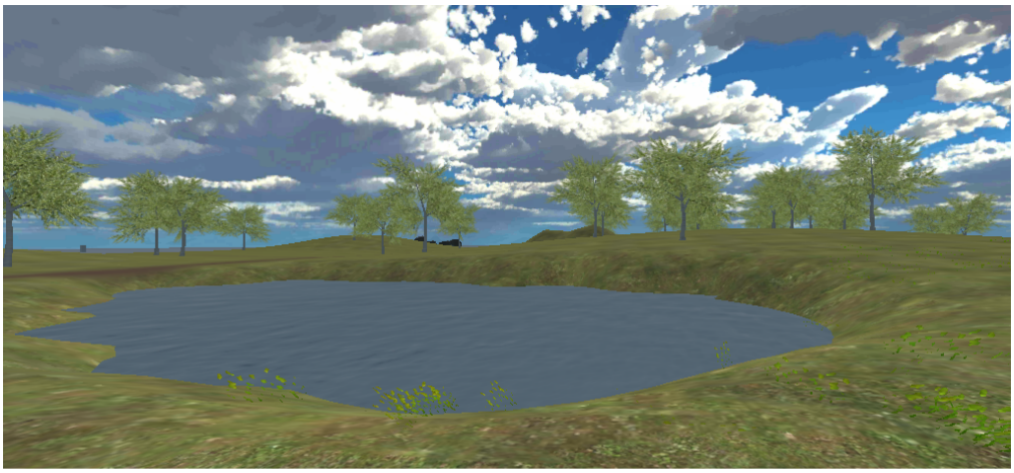
- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.2: Question 1

2. This makes me feel Uneasy

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.3: Question 2



3. This makes me feel worried

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.4: Question 3

4. This makes me feel relaxed

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.5: Question 4

5. This makes me feel uneasy

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.6: Question 5

6. This makes me feel worried

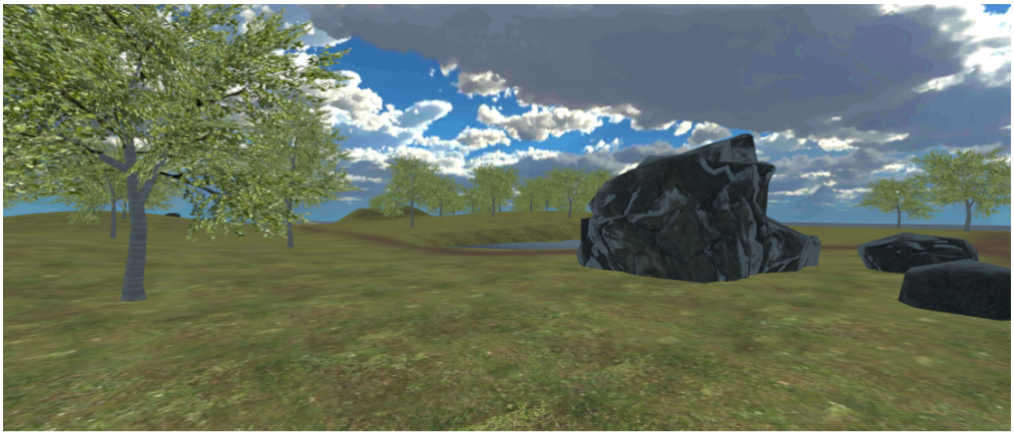
- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.7: Question 6

7. This makes me feel uneasy

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.8: Question 7



8. This makes me feel relaxed

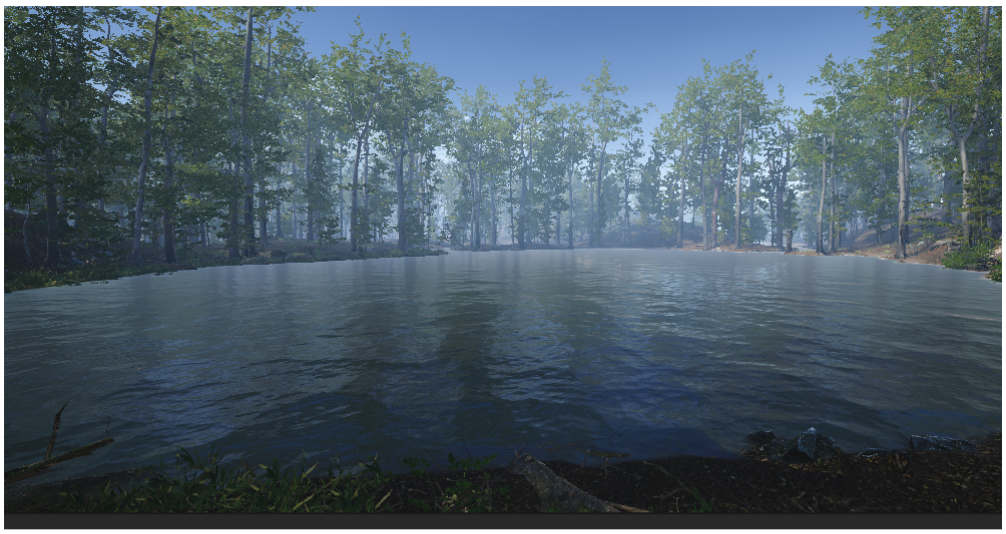
- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.9: Question 8

9. This makes me feel relaxed

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.10: Question 9



10. This makes me feel uneasy

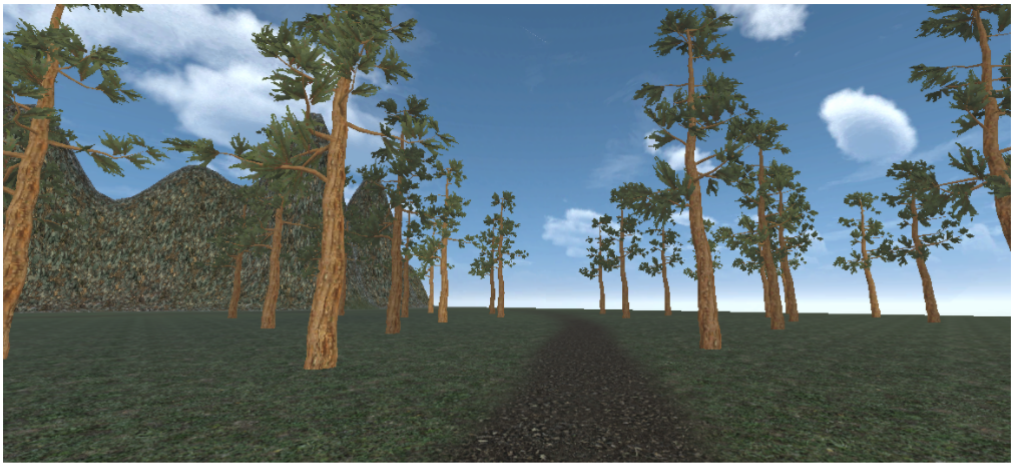
- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.11: Question 10

11. This makes me feel worried

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.12: Question 11



12. This makes me feel uneasy

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.13: Question 12

13. This makes me feel worried

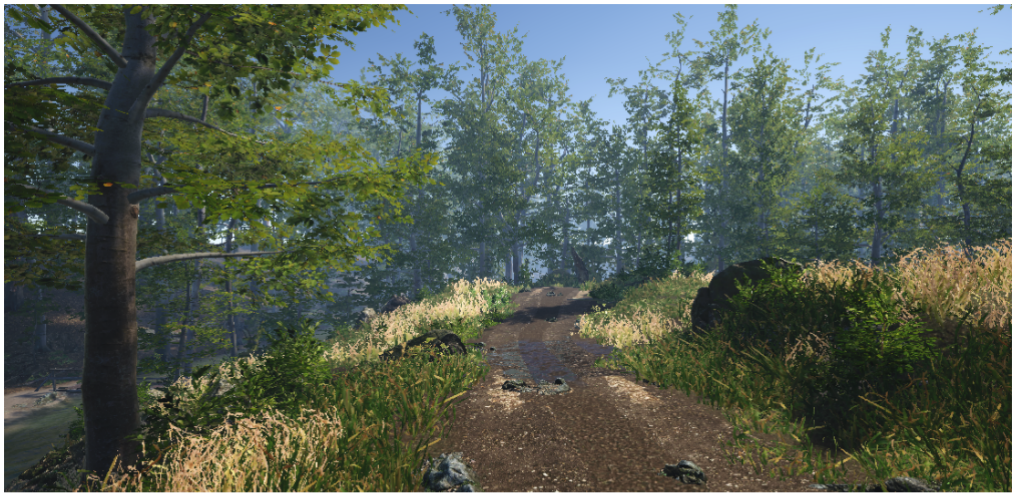
- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.14: Question 13

14. This makes me feel worried

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.15: Question 14



15. This makes me feel relaxed

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly Agree

Figure B.16: Question 15

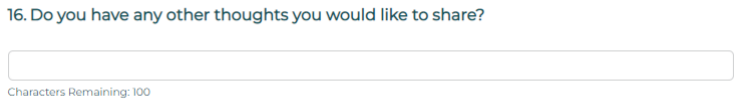


Figure B.17: Question 16

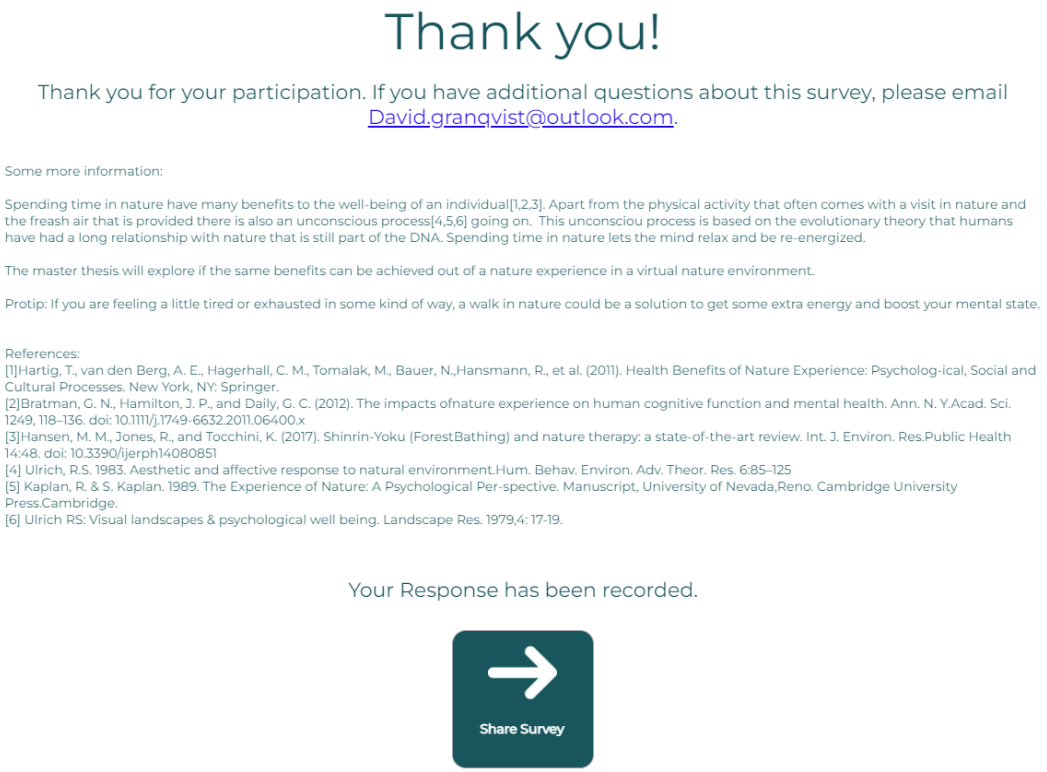


Figure B.18: Thank you page with some additional information

C

Appendix 3

C.1 POMS

ANGER:

- Angry
- Annoyed
- Bad-tempered
- Ready to fight
- Furious

CONFUSION

- Confused
- Mixed-up
- Uncertain
- Forgetful
- Unable to concentrate

DEPRESSION

- Depressed
- Miserable
- Unhappy
- Lonely
- Desperate

FATIGUE

- Exhausted
- Sleepy
- Tired
- Worn-out
- Sluggish

TENSION

- Anxious
- Nervous
- Panicky
- Relaxed
- Worried

VIGOUR

- Alert
- Energetic
- Lively
- Cheerful
- Carefree

C.2 Interview VR Test

- How do you feel right now?
- Can you describe your experience in the virtual world?
- What did you like the most?
- What did you like the least?
- Would you like to add anything to the experience?
- What did you think about the colors? like on the sky, on the trees, ground and so on
- What are your thoughts about the sounds?
- What did you think about the hands? Did you notice them much?
- What did you think of the means of transportation?
- Did you try to reach the edge of the world? Or try to exploit the system in any other way?
- Any other comments?

D

Appendix 4

Images from the VR environment.