VR Water Consumption Awareness

- Comparing a VR experience with traditional material, in terms of spreading awareness regarding water consumption -

Master Thesis

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Abstract:

This master thesis project is a collaboration project with Grundfos where a VR game was developed in order to investigate "How does a VR experience, using persuasive technology, fare against more traditional material, in terms of its effect on spreading awareness regarding water consumption". In order to design the implementation, various existing work was investigated in order to create an immersive and engaging experience. The implementation was compared to more traditional material in an evaluation regarding: spreading awareness, intrinsic motivation. An system usability scale and VR sickness questionnaire was also used to evaluate the VR experience. It was concluded that the VR experience was capable of spreading awareness, but that it did not significantly outperform the traditional material.

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Preface

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Chapter 1
Introduction

1.1 Motivation for Project

This project was carried out in collaboration with Grundfos within their accelerator program, where Grundfos was looking for students to carry out a virtual reality project. The specifics of the project was completely open, with the only requirement being the use of virtual reality.

Virtual Reality(VR) can be defined as one out of two forms, namely: "The first is totally immersive environments in which users wear head-mounted goggles to view a stereoscopic virtual world" and "The second form is screen-based and allows the user to interact with a responsive 'game-space"Castree et al. [2013]. In this report, the first definition for VR will be used, where the user wears head-mounted goggles to view a virtual environment.

1.1.1 VR and Behavioural Change

From talking back and forth with various Grundfos employees, it was decided that looking into behavioural change seemed fitting for a VR related project, specifically a video game experience.

People can experience positive health-related changes by playing video games. They are designed in such a way that they combine immersive stories, interactive properties, and behaviour-change technology Baranowski et al. [2008]. Dietary behaviour change can be one of the results of playing a multimedia game.The fun aspect of a game is the main factor which keeps the player's attention and may lead to a change in behaviour Baranowski et al. [2003].

Traditional behavioural interventions could benefit from aversive and appetitive stimuli. Games are a good example of a system in which the player makes decisions and feedback is given as a result. As an example, motivation and engagement is cultivated by combining positive reinforcement, negative reinforcement and punishment into the feedback. It is therefore suggested, that if you want to design a technology that brings behaviour change in users, it would be beneficial to use a system of reinforcements Kirman et al. [2010].

VR can be used to change people's behaviour and has been successfully used before to decrease nicotine addiction, abstinence levels and drop-out rates in cigarette ceasing programs Girard et al. [2009]. It is possible that immersion and emotional impact enhance self-reported presence. Therefore, higher immersion and emotional impact could lead to a more pro-environmental attitude. The same goes for narrative content and emotional Fonseca [2016].

Similar conclusions were reached by a study on what effect VR has on tourism and the attitude of people toward a destination. They found out that the sense of presence while being in VR is what causes the attitude change, thus confirming the persuasiveness of VR Tussyadiah et al. [2018].

1.2 Initial Problem Statement

The initial research showed signs of benefits from using VR in changing peoples' behavior and perception 1.1.1, which is translatable to teaching. Through initial discussions with Grundfos, it turned out that there was an interest in how VR can be used to explore water quality. Based on the initial research and the cooperation with Grundfos, the initial problem statement is formed.

"How can an interactive VR experience change a user's perception and enforce behavioral changes in relation to water quality?"

Chapter 2
Previous Work

2.1 Virtual Reality Used in Teaching Context

As mentioned in Section 1.2, behavioural change is related to teaching, therefor the next reasonable step would be to investigate the various aspects of VR in relation to teaching.

Virtual Reality simulations have previously been used to teach in various fields such as flight simulators, basketball, swimming and more.

Virtual Reality simulations can be used for high risk situations, where lives can be at risk or there is a lack of resources. One example would be nurse training, where nurse students can gain the basic knowledge about operations, before performing surgery on living subjects. It also provides more freedom to explore and show what would happen if something went wrong, or experience unusual and chaotic situations without putting lives in danger Stepan et al. [2017] Kilmon et al. [2010].

Virtual Reality has also been used to show and teach abstract concepts like dynamic forces in physics. It also allows for extreme closeups and therefore provides the possibility to explore extremely small objects such as molecules Stepan et al. [2017].

The learning outcome of using VR as a teaching tool has varying results, in a study about neuroanatomy, the learning outcome from using VR was similar to using traditional textbooks, however, using VR lead to a more engaging, useful, motivating and enjoyable learning experience Kilmon et al. [2010].

2.2 Engagement, flow and suspension of disbelief in relation to immersion

When engaged in a VR experience, or any experience in general, a user may experience a state of flow, making engagement an aspect of flow. When someone experiences flow, it is often referred to as "being in the zone", which lets a user experience: focused attention, loss of self-consciousness, intrinsic reward, interest and curiosity, as well as temporal distortion. In order to achieve the experience, a user must be faced with a task, that is balanced in relation to their own inherit skills. If the challenge is too easy, the user experiences boredom, whereas if the challenge is too hard, they will experience frustration Annie Jin [2014].

According to Baños et al. [2004], the experience that an individual has, can be described through the immersion they experience while engaged with the experience. The user is aware of their surroundings while doing so.

In extension, Wirth et al. [2007] defines immersion as also having the capability to create feelings of being present, or being part of a given game environment.

This would mean that engagement would be an action in which someone goes into or gets interested in something because of their personal motivations.

When considering creative work and trying to engage a user and make them immersed, the concept of “suspension of disbelief” becomes important. Rudolf Kremers Kremers [2009] takes note of the concept and defines it as “The ability to accept impossibilities in art and entertainment to better enjoy the work itself.”. Whether or not a user accepts these impossibilities is entirely subjective, but also depends on what type of work it is. If the work presents itself as an analogy to real life in both looks and function, the audience would have a harder time suspending their disbelief if things feel out of place or unrealistic. In contrast, fictional work has more freedom to apply non-real rules, sometimes even without being explained.

Because the enjoyment of the given work is directly tied to immersion, caution is advised when trying to address this trait. When experiencing the work of an author, users put their trust in the author’s capability to guide them in order to experience what was originally envisioned. Breaking their suspension of disbelief would then break the established trust, which in turn affects their flow negatively. In extreme circumstances, a user might give up and leave the experience entirely.

The traits mentioned so far are just some of what makes up the concept of immersion. If these traits are harnessed properly, the likelihood of a user to continue interacting also increases. A good implementation would not only keep a user interacting, but would also make them return again later in order to interact again. By not attending to the traits properly, immersion might break, potentially making the user stop the interaction completely.

Making a user disinterested, or even have a bad experience, should be avoided if possible. The long term effect could be that the user tells their peers about the experience they had, and encourage them to stay away, or write a review that affects potential users outside of their social circle.

Making careful considerations when planning the prototype for this project, and consecutively implement the features, should ensure that immersion will be achievable and sustainable. Making sure to periodically stress test the prototype should also make it more stable.

2.3 Immersion (spatial, temporal and emotional)

Since immersion is such a broad term, it can be a good idea to try and split it up.Ryan [2003] states that immersion can be split up into the following three types: spatial, temporal and emotional. Each of these immersion types can be related to a VR experience.

Spatial immersion
Is experienced when a user is immersed within the environment of the work, e.g. a game environment. It establishes a mental model and sense of the given place.

An example could be some of the world building techniques used for establishing where the user currently is, such as a map overview that shows them the whole world they are in, compared to where they currently are. It could also be the use of landmarks such as man made structures or natural phenomena. A user might feel the urge to go and explore the world in order to reach those far off places. The narrative story might also make use of the locations in order to situate what is happening. Being able to see the edge of the world, or through world geometry breaks the cohesiveness of the spatial immersion, thus it should be avoided. Colliders and inaccessible skyboxes and being unable to get close to far off objects make it possible to restrict the users placement in the world, which is where they would be perceiving the world from. This can be done more elegantly through proper level design such as natural cliffs or other features such as force fields, landslides or water.

Temporal immersion
Relates to the perception of time, very much like within flow theory. It creates a desire to experience what is yet to happen, in other words: suspense. Apart from suspense, it also affects how time itself is perceived.

An example could be that the user is presented with a sequential set of tasks, where whenever they complete a task, a new one is revealed in continuation of the previous task. It could be something as simple as going from A to B, where getting to B would reveal something to the user that has an associated task to it in order to progress further. By implementing features that a more directly tied to time, such as a time trial like a timed door, the effect becomes stronger if the user is capable of feeling this sense of urgency. The effect can be amplified by the addition of more features, such as hazards, that make the situation more challenging.

Emotional immersion
Is experienced when a user becomes emotionally invested in the given work.

An example could be that the user feels attached to a character due to their actions, behaviour or how they look. The effect can be amplified the more time they spend with a character, as more time is provided to build the character's relations with other character, as well as developing themselves.

2.4 Persuasion

According to Fogg [2002, p. 6], interactive systems allow for the effective use of persuasive techniques, making it relatable for a VR experience, or practically any other type of interactive system. An overview of various persuasive techniques should aid in designing solutions for conveying the content inherent in a system, more precisely referring to the experience achieved through the use of a given human-computer interaction.

2.4.1 Persuasive Technology

The purpose of persuasive technology is to change people's attitude and behaviour [Fogg, 2002, p. 1]. Persuasion can be considered to have two levels of influence, namely macro and micro. Macrosuasion is the larger scale persuasive intent of a system, while microsuasion would be the small scale elements used to achieve the larger scale intent. Microsuasion elements can be implemented within dialogue boxes, icons or interaction patterns, which could be achieved through praise and rewards, which in turn improves the effectiveness of a system [Fogg, 2002, pp. 17-19]. Video games naturally harbor microsuasion elements, even if the original intent is purely to entertain, as these elements persuade players to keep playing [Fogg, 2002, pp. 19-20].

2.4.2 Captology

Figure 2.1 shows what captology includes, namely the planned as well as intended persuasive effect of human-computer interaction. What is not considered, are the side effects such as children playing less inside compared to outside [Fogg, 2002, pp. 16-17]. Captology is also centered around the persuasive intent of a system, namely the endogenous intent. Exogenous intent, on the other hand, is when a system is used for a persuasive goal that it was never intended for [Fogg, 2002, pp. 16-17].

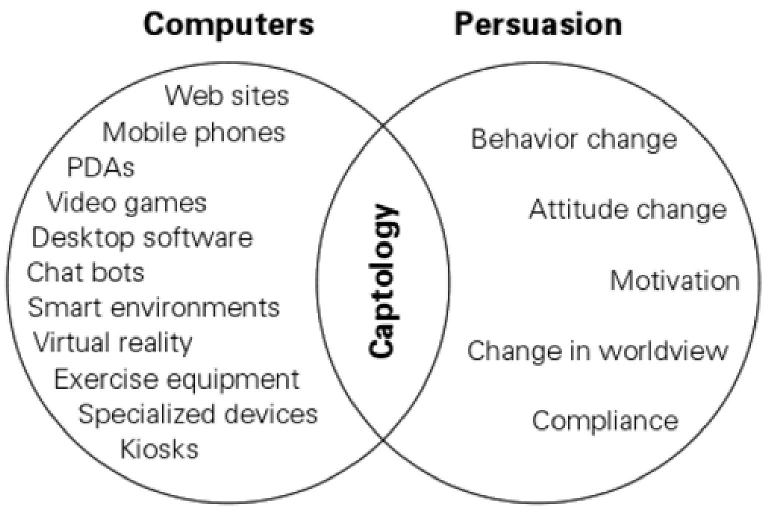

Figure 2.1: A visualisation of captology

In order to be effective, persuasive techniques have to be used in interactive systems where the techniques can be adjusted according to the situation Fogg [2002, p. 6]. Compared to traditional non-interactive media, persuasive technologies have an advantage because they are interactive. The interactivity allows the experienced output to be adjusted according to the needs and input provided by the user, as well as the situation, thus making persuasive technology a valid replacement for a human persuader. Compared to a human persuader, whom can also adjust their response, computers have the six following advantages [Fogg, 2002, pp. 7-11]

1. **Computers cannot get tired**, allowing them to be more persistent.
2. **Information shared with a computer is more anonymous**, making it easier for people to share information with it.
3. **Computers can manage and utilise large amounts of data**, as they can access data faster and can have more of it.
4. **Can be used to present information**, due to the availability of many modalities.
5. **Software can scale easily**, meaning that computers can take on a specific role faster and easier.
6. **Computers can be ubiquitous**, making them have an easier time being allowed into personal spaces, where human persuaders do not [Fogg, 2002, pp. 7-11].

2.4.3 The Functional Triad

[Fogg, 2002, pp. 23-24] created a framework for categorising the various roles that computers can embody. How people use or respond to a system is outlined along with overarching theories regarding persuasion. The framework can be seen in Figure 2.2.

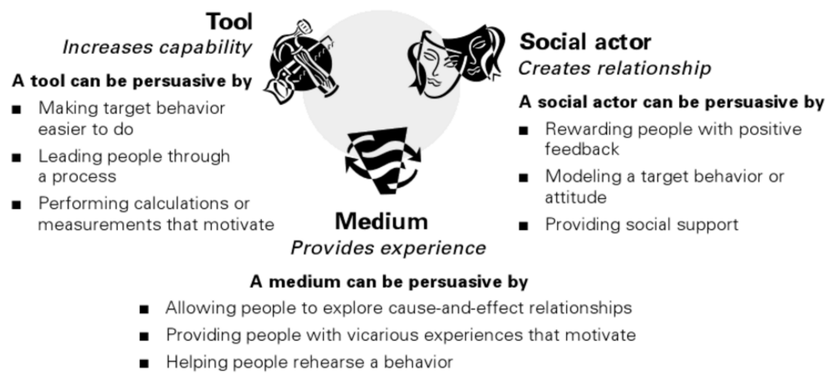

Figure 2.2: A visualisation of the functional triad

Usually, a system that include human-computer interaction consist of a blend between the roles present in the functional triad. The persuasive strategies used, depend highly on which role is being acted out through the experience [Fogg, 2002, pp. 23-24]. The following sections expand upon the three roles.

2.4.4 Computers as Tools

On the left-hand side of the triad 2.2, computers as tools is represented and consists of seven types of tools that use different approaches to change the attitude and behaviour of a user [Fogg, 2002, pp. 32-52].

1. **Reduction technology** is centered around the idea of simplifying the interaction needed in order to achieve the desired outcome, while keeping the interaction short and simple. It is suggested within psychological and economical theories, that humans seek to minimise costs while maximising gains, which in this case would make the technology easier to use and therefore more accessible. In other words, improving the persuasive potential by simplifying the interactions.

2. **Tunnelling technologies** are used when the experience is laid out on a linear path or track that the user cannot divert or return from. Furthermore, the user is forced to experience everything that the experience entails. This results in an action and response limited experience that the user voluntarily exposes themselves to, in other words, guided persuasion. The effectiveness of this methods comes from the natural wish for consistency when dealing with

users, where once a person is committed to something, they usually stick with it.

3. **Tailoring technologies** utilises a users' input in order to change their attitude and/or behaviour as a response. In other words, the experience is tailored to the specific user, which makes the experience more relatable and relevant. This, in turn, increases the likelihood of the user changing their attitude or behaviour. Psychology backs this up, as generic information is less effective than tailored information, which is persuasion through customisation.

4. **Suggestion technologies** aims at suggesting a change in behaviour at the right moment, which increases its chances of success. Getting the timing right cannot be guaranteed as there are no strict guidelines for it, so to make this approach more successful, one has to consider as many aspects of the persuasive technology as possible. If the timing is off, it lowers the chance of success for making the user listen or find the information relevant.

5. **Self-monitoring technologies** makes it possible for a user to monitor their own behaviour and attitude in order to adjust them according to a predetermined goal or outcome. In order to be effective, it has to be working real-time and require a limited amount of user interaction, while also providing feedback to the progress towards a users goal.

6. **Surveillance technologies** uses persuasion through observation in order to modify the behaviour of the observed people. In order to have an effect, the surveillance has to be obvious and apparent to the person being observed, as being consciously aware of being observed is what causes the change. If the person is not behaving as intended, it is important to not enforce punishment upon them.

7. **Conditioning technologies** provide rewards and positive reinforcement in order to alter a user's behaviour. In order for this method to work, the reward has to be provided whenever the desired behaviour is carried out by the user, with the effect being amplified if rewards are unpredictable.

2.4.5 Computers as Media

On the right-hand side of the triad 2.2, computers as persuasive media is represented, which can be separated into two categories, namely: symbolic and sensory. Both can be used to affect people, but in terms of captology, the focus is the use of sensory media which includes audio, video and even olfactory as well as tactile sensations, which can be used to create vivid simulations that motivate and persuade. The effect can be quite powerful due to the experience principle [Fogg, 2002, p. 61]. As people usually react to simulated environment as if they were real world experiences, the reaction allows influence dynamics to kick in. Computer-based simulations can be split into three different types, with the importance being the user experience.

1. **Simulated cause-and-effect scenarios** enables the user to quickly see the effects of their interaction without the need to wait, as well as represent these scenarios in vivid and appealing ways [Fogg, 2002, p. 63]. By visualising the cause and effect, users can be persuaded through the understanding of the experience, without any real-world consequences. Due to the safe environment, users can freely explore and put into effect new attitudes and behaviours. Their findings can then be applied within a real-world context, thereby causing actual change. Simulations can be very subtle in the way that they persuade, where users are not actively aware of the biases that were built into the simulation, due to them being engaged and immersed. It is practically impossible to create a simulation that does not contain at least some level of bias from the side of its creators. There are simply too many variable which cannot be predicted accurately [Fogg, 2002, p. 68]. Unfortunately, being transparent towards the user is oftentimes unwanted, impractical or ineffective, with no standardised approach to inform the users. It is also possible that the creators themselves are unaware of their inherent biases [Fogg, 2002, p. 68].

2. **Simulated environments** are achieved by providing new surroundings to the user. Even simple systems can become engaging due to immersion being a function of the mind, rather than that of technology [Fogg, 2002, p. 69]. These types of environments exist within a controlled and safe environment, hence they have no real-world consequences. Furthermore, they can also be stopped, started or returned to as the user sees fit, making it possible to explore other behaviours and attitudes at their own pace. Fogg [2002, p. 69] describes how the persuasiveness of the environments is a result of letting users practice a given behaviour, as well as control what they are exposed to in terms of new situations. Users can also act out facilitated role-play, where the user can adopt the persona of another character. Most important to note is that the environments present in an experience play a key role in shaping the behaviour and attitude of the user, making simulated environments persuasive [Fogg, 2002, p. 70]. In order to be successful, a user would have to apply the experience they gained from the virtual world, in a real world context [Fogg, 2002, p. 77]

3. **Simulated objects** use real-world settings in order to provide an experience close to an everyday context. Because the simulation is situated in reality, there is a direct connection between the experience and the daily routines of a user. Due to the tangibility inherent in simulated objects, there are less

dependencies on imagination and suspension of disbelief affecting the persuasiveness of the given work. In turn, users are also more likely to have they behaviours or attitudes affected through such an experience. Therefor, motivating changes in behaviour or attitude is very clear as object simulations use the principle of simulations in real-world contexts [Fogg, 2002, p. 77].

2.4.6 Computers as Social Actors

The bottom section of the functional triad 2.2 covers computers as social actors, which consists of five types of social cues, that affect how people infer social presence in a computer based solution Fogg [2002, pp. 91-115].

1. **Persuasion through physical cues** relies on physical cues in order to create a social presence within persuasive technology. Through the presence of a character, one can use its physical characteristics such as its eyes, mouth and body movement, in order to cause interest in the user. Attractiveness is important to consider, as a physically attractive character produces the halo effect. The halo effect makes a character seem to have more admirable qualities such as intelligence and honesty. These properties can also be transferred to non-character elements that provide feedback, such as pop-up windows or the general look of the experience.

2. **Using psychological cues to persuade** can be accomplished by implementing signs of personality within the experience, which in turn provides nuanced feedback and makes the persuasive technology more relatable. People are generally more inclined to be persuaded by computers that are similar to their own personality and affiliation Fogg [2002, p. 97].

3. **Influencing through language** makes it possible to increase the persuasive potential of the experience by using various language traits. One trait could be that the experience is given a specific language colouration, or referring to the user by name or using praise.

4. **Social dynamics** are the various rituals that people enact when interacting with each other, such as forming queues or introducing themselves to other people. Implementing social dynamics into an experience, would make it seem more genuine and possibly invoke the same response as if it were a real-world scenario. A common feature within social dynamics is reciprocity, which means that users are inclined to interact if offered help by the computer.

5. **Persuading by adopting social roles** can be accomplished by making the experience enact a social role which is relevant to the subject matter. It makes the social acto appear more suited for the task of helping out, and in turn, makes users more inclined to receive that help, or in general, learn and be

persuaded by the technology. This concept goes for both authoritarian and non-authoritarian social roles.

Application of Persuasive Technology Sum-up

In general, persuasive technology is designed around changing the attitude and/or behaviour of users, which is achieved through captology. Captology is split into three roles that computers can take on, also known as the functional triad. Therefor a computer can carry out the role of a tool, medium or social actor, or any combination of the three. Captology will be taken into account while designing and implementing the VR experience as a persuasive technology for this project.

2.5 Water Quality

In this section, issues about water scarcity will be discussed, focusing on the water quality needed for drinkable water, water pollution and the amount of freshwater. The information is mostly based on slides and material provided by Grundfos, where the general theory about water quality and availability is based on an interview with Christian Schau, a Grundfos application manager [Schou, 2018]. He works within water utilities, which means that he is responsible for the development of an application for water utility customers. A transcript of the interview can be seen in Appendix A.

Most of the earth is covered with water, roughly 71%, however only 3% of the water on earth is freshwater that is drinkable. Roughly 1% of the water is available since some of the freshwater is unavailable due to being frozen in ice caps and glaciers or other. Since the earth's population is estimated to reach 9 billion people at 2050, the need for drinkable water will increase. It has been estimated that the need for water will increase by 30% by 2030. Modern societies often spend more water than is reproduced, meaning that the groundwater is spent faster than it can be replenished. It is estimated that roughly 65% of the world's population will live in water stressed areas by 2025. The problem is already severe, as around 783 million people do not have access to safe drinking water. The number is estimated to increase to 1.5 billion at 2025.

The water usage in modern societies is largely distributed within industry and agriculture, whereas only 10% of the water consumption is being used as drinking water. In some cases, badly designed water distribution systems cause clean water to become unsafe for human consumption. Water is usually also delivered with huge losses due to e.g. leaking pipes, with severe cases of up to 80% of the water leaking throughout larger cities. Approximately 60% of the world's freshwater withdrawals goes towards irrigation usage, whereas only half of this is reusable and the rest being lost as wasted water. Another issue regarding water is pollution which ist unsafe for human consumption. In certain cases, up to 70% of industrial waste is dumped into the water, causing pollution. Unclean water can have severe effects if consumed by humans, it can lead to several diseases and in worst cases death.

2.6 Water Quality and Water Purity

When talking about water and using water, it is important to know the difference between water purity and water quality. Water purity is, as the name suggest, how pure the water is, where pure water would be H2O. Water Quality is not about pure water, since the water can contain bacteria, minerals, salts and more without making it safe for consumption. It is therefore known what kind, and how many, of each type of bacteria is in the water, which minerals are present and whether it contains harmful vira or not. So water quality is about assigning a human defined quality to the water that is needed for a certain purpose, knowing what is inside the water and knowing what different quality of water can be used for. Hence it is possible to categorise and measure the amount of pollution in the water, leading to a proper quality classification, which then can be compared to the human set standards for water quality. This can induce problems, when looking for new water sources, since the waters' quality needs to fulfil the standards set for the application field of the water.

2.7 Water Scarcity and its Challenges

Water Scarcity is closely related to water availability and is the balance between water production and water consumption. It is important to note that water scarcity is therefore a mass balance rather than having or not having water. It means that you can have water available to you, but you will soon or eventually run out because you are consuming more than is being produced. This also means that the impact of water scarcity will not be felt unless insufficient amounts of water is being produced, or a government starts legislating or rationing water.

2.7.1 Grundfos: The Cape Town Challenge

Due to the nature of water scarcity, it is therefore not enough to simply produce more water, as it is statically shown that it is not sustainable to continue consuming like the world is doing currently. In contrast, it is thought that acting and thinking in ways of using less water is more relevant than making more water available by either finding it or running non-usable water through a process that makes it usable.

This leads to the Grundfos cape town challenge, which is closely related to the current situation in Cape Town, South Africa, where water scarcity is threatening their availability of water. The issue has escalated to the point where each person's access to water is being limited by the government. The Grundfos challenge is to limit ones daily usage of water to 50 liters pr. person.

2.8 Water Recycling

A way to address the looming issues that follow water scarcity, is the concept of recycling or re-using water, before returning it to the sewage system. Within a household, there are three factors that influence whether water can be re-used. The first is the outlet of humans, any water that has been in contact with human refuse, is considered non-reusable. The second is any water that has been in contact with garbage containing dirt or any organic material that can foster the presence of vira. The last one is water that has been in contact with chemicals that are unsafe for human consumption, e.g. soap used for cleaning dishes. This is also in relation to substances such as beauty products and pharmaceuticals.

Although water that has been in contact with food seems to be outside the frame of re-using, as long as the water has been boiled, it has been disinfected and can therefore be used anyway.

Apart from the household being an application field, there are also other solutions that can have a larger impact, such as a dry cleaning facility where they can handle larger batches of clothing, while also being able to re-use water more conveniently.

2.9 Health Related Issues Caused Through VR

VR comes with its adverse health effects such as general discomfort, disorientation, nausea, dizziness, headaches, vertigo, drowsiness, pallor, sweating, and, in the occasional worst case, vomiting. The cause for these side effects can be self-motion through the environment, physical hazards, poor hygiene, incorrect calibration and latency [Jerald, 2015, pp. 163].

The most common health ailment experienced within VR is motion sickness. It can occur when there is a difference between what the person sees and what he feels is around him, therefore a loss of orientation [Jerald, 2015, pp. 163]. One of the causations of VR motion sickness is scene motion. Scene motion happens when the entire virtual environment would move in an unnatural way. There are two types of scene motions, unintentional scene motion and intentional scene motion. Unintentional scene motion is caused by technological shortcomings such as inaccurate calibration or latency in the display. When there is too much scene motion it can lead to a degraded VR experience, motion sickness and a reducing task performance. Intentional scene motion is when the virtual world moves as intended, though not necessarily as if it was the real world equivalent [Jerald, 2015, pp. 163-164].

VR motion sickness can also be caused by vection, but that does not apply to all the cases. If constant linear velocity is used, motion sickness does not occur. In contrast, motion sickness could be experienced if the scene moves with non-linear velocity, e.g. accelerated velocity. Vection can happen when there is a mismatch between the motion in the visual scene and the physical motion of the user, with the effect being increased when acceleration is involved. When the virtual scene moves with a linear velocity, one does not sense physical velocity, meaning that the body has nothing to compare with in the visual scene in relation to the real world. In contrast, virtual rotations are easier to pick up [Jerald, 2015, pp. 164].

Other less influential factors that can induce motion sickness are head bobbing, hill terrain and stairs. Lateral movement can also cause motion sickness, since people don't strafe in the real world [Jerald, 2015, pp. 164-165].

Chapter 3
State of the Art Products

In the following chapter, state of the art regarding human-computer interaction experiences, in relation to both VR and non-VR, are outlined. The topics that are outlined concern: water scarcity, teaching, persuasive technology as well as implementations that are relatable to environmental cause-effect scenarios.

3.1 Persuasive Games

3.1.1 PowerHouse

"PowerHouse" is an implementation of persuasive technology as a non-VR video game. The goal is to create better awareness towards energy consumption, while in turn affecting the behavior of the engaged user. Whether or not it is successful is yet to be determined however, as it has not been tested in relation to its ability to alter attitude and behavior.

The player is situated within the context of a simulated reality TV show, where seven characters are controlled and need to be kept happy for as long as possible. A screenshot for reference can be seen in Figure 3.1.

Figure 3.1: The meters in the lower panel display a specific character's mental and physical state. In the upper right corner are the money and power meters that show the accumulated points and how much energy is being consumed.
Source: Bang et al. [2006]

Apart from keeping the characters happy, the player also has to manage energy consumption, where almost any action requires it. As a reward for doing well, the player is earns points that can be used to purchase various items that help in satisfying the needs of the characters.

3.1.2 Drawn to Distraction

"Drawn to Distraction" is a video game that was created in order to promote an understanding of Attention Deficit Hyperactivity Disorder, in short, ADHD [Goldman et al., 2014, p. 115]. The target group consists of both the general public, but also caretakers of people who has this disorder. Rather than making a realistic representation of real life, an abstract take on the concept is used instead. By doing so, it is possible to downplay and emphasize where it is needed [Goldman et al., 2014, p. 115]

The player controls a character that has to get to the schools library, which will allow them to study for an upcoming exam. In order to accomplish this, the player also has to get there within a certain time frame. The effects of ADHD is represented by the slowing of time when moving around, which makes the task more tedious. In contrast, the player is presented with the option to play a minigame called "Space Raiders",as seen in Figure 3.2, where time flows a lot faster. Along the way, the character's thoughts are also shown in thought boubles.

Figure 3.2: The character is going down the corridor, with thought bubbles appearing along with the option, in form of the bubbles with images, to play the mini-game.
Source: Goldman et al. [2014]

The distraction gradually become hard to avoid as the player makes progress towards the library. The main conflict consists of how short-term tasks are easier to achieve, and more convenient, while the long-term tasks are harder, and more tedious [Goldman et al., 2014, p. 117].

Results from testing "Drawn to Distraction" were inconclusive, as issues with the questionnaires arose, as well as the small sample sizes achieved Goldman et al. [2014, pp. 119-120]. The final experiment, however, did show a trend towards empathy and understanding being achieved [Goldman et al., 2014, 120].

3.1.3 First Person Victim

“First Person Victim”, or FPV for short, lets the player experience a wartime scenario from the perspective of a civilian, or in other words, a war victim. The purpose was to investigate engagement, in terms of how a player is affected through the experience of a serious topic. The study suggested that:

> *"it is possible to use conventions from playfulness and player engagement which are usually related to enjoyable experiences to drive users through narrative game-like experiences, which can mediate unconventional content and communicate serious topics"[Schoenau-Fog, 2012, p. 67].*

The statement addresses how a serious message can be conveyed through an enjoyable experience. An issue with FPV is that of missing extrinsic goals, which left participants wandering around in a lost state of mind. Furthermore, the game is relatively unstable, causing situations that potentially break immersion, or the entire experience itself.

3.1.4 My Cotton Picking Life

My Cotton Picking Life is a click-based game about forced labor in the Uzbekistani cotton fields. In the game, the user works in a cotton field and is supposed to pick 50 kg of cotton by pressing two buttons. If the user stops pressing the buttons, the game will scold the user for not picking cotton. The game allows the user to opt out at any point, where you will be presented with how much you managed to pick up, how much money you would have earned and how much time you spent collecting cotton. [Tomas, 2018]

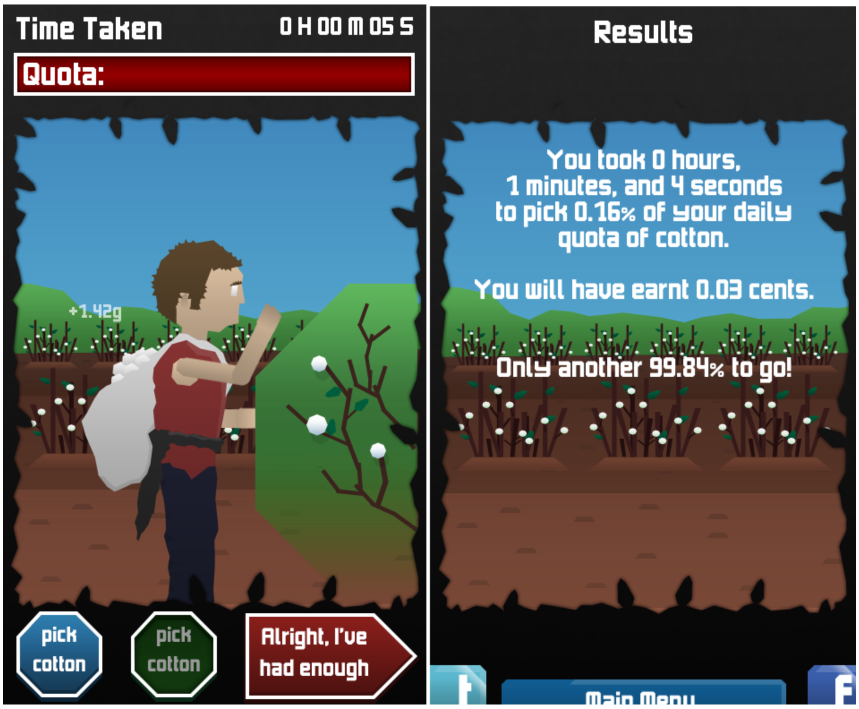

Figure 3.3

Ruud [2016] used the game to compare the persuasive potential of changing attitude, compared to a youtube video which covered the same topic. The article showed that those who played the game, felt that picking cotton involved a greater workload, compared to those who watched a video. In both cases, people's perception about the workload of picking cotton increased from pre- to post questionnaire.

3.2 Persuasive VR

3.2.1 Effect of Immersive (360° Video on Attitude and Behavior Change

The project tests if a 360° video can effects users perception about environmental issues and how they perceive meat, and whether the movie can cause change in behaviour. The project also tests, how a VR experience compares to a tablet experience. The results shows that people viewing the video in VR was more willing to reduce their meat consumption, than those viewing the video on a tablet, whereas those watching the control video was even less willing to reduce their meat consumption.

3.3 I, Chicken and I, Orca

PETA has completed two VR projects, "I, Chicken" [PETA, 2014] and "I, Orca" [PETA, 2018]. In "I, Chicken" you play as a free-roam chicken and it takes you through the process of being a free-range chicken that is taken to the slaughter house. "I, Orca" allows the user to explore the oceans as an orca, while talking about the cruelty that is done to orcas in SeaWorld. Eventually you meet a *mother* orca which mourns, because her baby was taken from her and sent to SeaWorld, where the baby orca is living a miserable life in captivity. These games try to raise awareness regarding animal treatment in places such as sea world and chicken slaughter houses, through empathy and ethical mindset.

3.4 EcoMUVE

EcoMuve [Harvard, 2018] is a 3D computer-based virtual environment that recreates and simulates an ecosystem in a pond. It is designed for children, and its purpose is to teach them basic biological processes like photosynthesis and decomposition as well as environmental issues that can happen in the particular ecosystem [Lang, 2014].

3.5 Using virtual reality and percolation theory to visualize fluid flow in porous media

A tool called VRFluid was made, and used, to visualise fluids in VR. It makes it possible to create various simulations and see what happens in areas that one does normally not have access to, such as within pipes or the formation of oil deposits. The system is flexible enough to simulate various fluids that have different properties [Lima et al., 2013].

3.6 Immersive virtual reality as a teaching tool for neuroanatomy

Surgical theatre [Surgical Theater, 2018] provides a safe space for either training medical students, or as a tool for comforting and informing a patient before surgery or similar. A major strength is that there is little occlusion so that a user can see what is going on under the skin and so forth. This approach provides a higher level of fidelity compared to two dimensional black and white scans that are common throughout medical facilities. Surgeons can also get a better idea on how to best approach surgery as they can get a three dimensional representation of the real world case and explore freely. Stepan et al. [2017] investigated its effectiveness within teaching, but there was no significant difference in their knowledge. The tool did provide a significantly more engaging, enjoyable and useful by the test participants.

3.7 State of the Art Sum-up

The state of the art research indicates that persuasive technology can be applied within the context of a VR experience, and be used to change the behaviour of a user. Previous implementations within the context of VR exists, though they are limited in both what can be experienced, as well as in terms of relevant research into the topic. Though most of the persuasive experiences are not within the context of VR, they still provide an indication of what can be achieved when trying to develop something that is intended to persuade as its main objective, rather than being a byproduct of the natural capabilities within games.

The most prominent research has been in relation to teaching applications of VR, though mostly focusing on visualising something that can normally not be seen as it is hidden away underground or behind other material. This would indicate that the main focus for previous implementations has been to utilise the capabilities of VR to overcome some of the shortcomings of more traditional persuasive technology implementations, rather than to investigate its persuasive effectiveness.

Chapter 4
Design and Implementation of VR Prototype

4.1 Final Problem Statement

In Chapter 2, it was shown that VR has potential as a teaching outlet and has already been used in fields like training doctors to perform certain operations. It was also shown that the world has a lack of water in the future, due to population growth, causing a growing need for drinkable water. The issue only increases due to water pollution and wasting water, due to e.g. leaking pipes. This causes a shift away from a VR experience about water quality, towards a VR experience that is about water consumption.

Since behavioural change is a tough topic to investigate as it requires several evaluations that are also long term, meaning they are far apart, it was decided to be out of scope for this project, which resulted in a downscale of the problem to be about awareness instead. This allows for more time and focus being spent on implementing a more wholesome prototype, which will have a significantly better chance at performing well in an evaluation. Although this means that behavioural change is no longer the focus, it does not mean that the prototype wont be able to provide it.

Regarding engagement, the importance of having a balance between the users' skill and the challenge presented by the media to prevent either boredom or frustration was investigated. Achieving immersion, through engagement, would give the users a sense of presence inside the virtual world, increasing the persuasive potential.

By looking into various concepts from persuasive technologies, an overview of potential methods to implement during design was established. By incorporating these methods correctly, the persuasive potential of the prototype should be improved.

Based on the research done throughout Chapter 1 and Chapter 2, the following problem statement has been established.

"How does a VR experience, using persuasive technology, fare against more traditional material, in terms of its effect on spreading awareness regarding water consumption."

In addition to the problem statement, the following research questions will also be investigated:

"How does the VR experience fare against the traditional material in term of enjoyment and interest"

"How does the VR experience fare against the traditional material in term of its value and usefulness in spreading awareness"

"How does the VR experience fare against the traditional material in terms of pressure and tension, while interacting with the experiences"

4.2 General Strengths and Weaknesses of VR

Before developing a concept, it was decided to take a step back and look at the more general strengths and weaknesses of VR in order make the best use out of the technology.

Strengths

VR provides several features that can be considered strengths of the technology, though not necessarily exclusive. Through VR, one is able to experience a risk free environment that can be very close to the real world equivalent. Due to the nature of VR, it has a higher potential to better mimick a real world equivalent. Another strength is the ability to get very close to objects without them going out of the boundaries of a regular screen. Through added modalities such as haptic feedback or the ability to move further away than a designated area, the strengths of VR would be further amplified, as well as create new forms of interaction.

Weaknesses and Constraints

Unfortunately, VR also brings various weaknesses and constraints, some being almost exclusive to the platform. The hardest weaknesses to overcome are the health impact related weaknesses, which are tied to how content is implemented and being represented through the device. Other weaknesses such as weight, calibration and maintenance are all factors that can affect the health of a user. Furthermore, the cost of VR devices themselves, as well as the hardware needed to run the software, is also one of the current weaknesses, though it is likely to change along with the availability and development of VR devices. Another current weakness or constraint, is the limited space one has for using VR as well as the use of either a tether that restrains reach, or a battery that restrains usage time. Since any VR experience will be experienced from the perspective of the user, there are also limitations on which camera control options can be used.

4.3 Implemented Concept

In order to address the problem statement 4.1, the first task was to come up with a fitting concept. The game follows a linear story, where the player goes through everyday activities that requires usage of water. When the game starts, the player is situated at the entrance to a countryside house. They have just arrived home from work and is welcomed by their AI home assistant, which acts as a narrator and guide. The player is then introduced to a sequence of minigames, which either require the consumption of water in order to be carried out, or lets the player install water conserving improvements. As the player progresses and completes minigames, the AI assistant will compliment the player and also give information about water consumption in relation to the minigames. Once the player has finished all minigames, they can go to the living room where a projector shows how much water was used for the individual tasks, compared to the recommended amount. The storyboard in Section 4.4 outlines the entire experience from start to finish.

For a more technical aspect of the code implementation within Unity, go to Appendix C.

4.4 Storyboard

The exact AI narration can be seen in Appendix B.

1. The player arrives home after a day of work
2. The narrator welcomes the player, and reminds them that they need to install a new shower head in the bathroom.
3. The player goes to the bathroom and sees an open package with a new shower head inside.
4. The narrator introduces the "install shower head" minigame, and what needs to be done.
5. After the minigame is complete, the narrator informs the player about benefits of replacing old shower heads with new ones.
6. The narrator tells the player there are leaking pipes in the boiler room.
7. When entering the boiler room, the player can sees several leaking pipes, and a wrench on a table.
8. When reaching the wrench, the narrator explains the "fix leaking pipes" minigame to the player.
9. After the minigame is complete, the narrator informs the player about water waste caused by leaking pipes.
10. The narrator comments that the player is looking a bit hungry and suggest them to go to the kitchen and prepare some food.
11. When arriving at the kitchen, the player sees a sink, a bowl of dirty potatoes and a potato peeler.
12. As the player gets close to the sink, the narrator introduces the "peel potatoes" minigame.
13. After the minigame is complete, the narrator informs the player about how even small changes can improve your overall water consumption.

14. The narrator tells the player to go and pour water from yesterdays meal into the plant pot.
15. At the far end of the kitchen counter, in the corner, the player can see a plant pot and a pot full of water.
16. After completing the minigame, the narrator informs the player about re-using water.
17. The narrator tells the player that the house is looking a bit dirty and suggests that they clean it.
18. The player sees a bunch of dust and liquid spots on the floor and goes towards the cleaning utensils.
19. The narrator instructs the player how to complete the "cleaning" minigame.
20. Once complete, the narrator informs the player that water isn't always needed in order to clean the house, and suggests alternatives such as paper towels.
21. The narrator tells the player to go and flush the toilet in the bathroom.
22. In the corner of the bathroom, there is a toilet with a flush button on the cistern.
23. Once pressed, the narrator will inform the player about old versus new toilets, and also small tips on when to flush.
24. The narrator tells the player that all their tasks are done and suggests them to go and take a shower to relax.
25. The player sees a shower in the bathroom, along with a piece of soap on a small holder on the wall (the same they installed the showerhead on).
26. When the player gets close, the narrator tells the player how to complete the "showering" minigame.
27. Once completed, the narrator informs the player about the difference between using a shower and a bath tub, as well as a more water efficient method of showering, namely start-stop showering.
28. The narrator states how the player has now completed all tasks for the day and suggests that they can go to the projector in the living room in order to reflect on their water consumption.
29. In the living room, the projector shows the amount of water that was used for all the tasks.
30. The end.

4.5 Mini Games

There are several types of mini games which are used to engage the player, and as a segway for the AI home assistant to talk about various water related topics.

4.5.1 Install the Shower Head

In the bathroom you are presented with an unpacked shower head that has to be mounted instead of the current one. First you have to detach the current shower head by twisting it counter clock-wise till it pops out of its socket, then put it into an empty box. Once off, you have to pick up the new shower head and move it up to the mount where you rotate it clock-wise until it is installed. The AI talks about water-reducing shower heads.

4.5.2 Fixing Pipes

There are some exposed pipes in the water boiler room where water is leaking out at the pipe connections. This can be fixed by tightening the nuts with a wrench. This is done by picking up the wrench and moving it into position, then twisting it clock-wise. Once all leaks have been fixed, you are done. The AI talks about how leaking pipes are one of the major factors in wasting water in major cities.

4.5.3 Cook Food

In the kitchen, you have to prepare and cook some potatoes. In order to prepare the potatoes, they have to be peeled and cleaned. The player can decide to clean the potatoes before peeling them, but it will consume extra water as the potatoes will have to be cleaned after peeling as well, as there will be a bit of grimy dirt left over after peeling them. The faucet has a 3d bar which shows how close you are to the optimal usage of water. There is also an indicator that shows how many liters of water that has been used specifically. There is a total of 3 potatoes that need to be processed, and the player is capable of carrying up to 2 at a time, one in each hand. Each potato needs to interact with the peeler 3 times before all the skin has been removed through a dissolve shader. It is possible for the player to peel all potatoes and put them back into the bowl before they are cleaned. This makes it possible to prep all the potatoes and then quickly rinse them off without having to switch to the peeler or keep one hand occupied by carrying the peeler. The player is also capable of turning the water on and off while carrying items. In total, the potatoes can be in 1 of 3 states, namely: "dirty", "half-clean" and "clean". Once all potatoes are peeled, clean and placed in the bowl, the minigame is finished.

4.5.4 Clean Floor

Parts of the floor are dirty with either dust or liquid which the player has to clean. The player can choose to use a mop and bucket of water for all dirty areas, but more water can be preserved by using a vacuum for the dust. If the vacuum is used on the liquid areas, they get smeared out, resulting in it being harder to get off and requiring more water to be cleaned, as it has been dried out. The water bucket has a 3d bar that shows how close you are to exceeding the optimal amount. The optimal process is to vacuum all the dust and only use the mop for the liquids. An indicator on the bucket shows how many liters of water that has been used so far. The vacuum is used by moving the hand to the handle and pressing the trigger in order to pick it up. Once picked up, the player can let go of it by moving their hand "away" from the handle by moving it up or down in world space. The vacuum is glued to the floor, so it will only move along the plane of the floor. When holding the vacuum over a patch of dirt or liquid, the trigger can be used to turn the vacuum on. After holding the vacuum on a spot for a while, it disappears. Once all the patches are gone, the minigame is finished.

4.5.5 Take a Shower

In the bathroom, there is both a shower and a bathtub. Once the minigame starts, the player gets a torso that moves along with their head motion. The player then has to clean their torso by using the shower. In order to get clean, the player has to moisten up, soap in and subsequently rinse their chest, which is covered in dirt. The player has the option of letting the water run throughout the entire shower bath, but the optimal solution is to first moisten up in order to apply soap, then rinse it off once it has been properly soaped in. Trying to apply soap without applying water first, will result in failure to do so, as no soap bubbles will be applied. In order to show progress, a shader is used to overlay a scrolling water texture, as well as dirt that changes color when soaped in, as well as dissolving when rinsing off with water. A 3d bar built into the shower frame shows how close the player is to reaching the optimal use of water. An indicator on the shower indicates how many liters of water that has been used so far. The AI talks about how to optimise water consumption when taking a shower, as well as how bath tubs consume even more.

4.6 Minor Interactions

On top of the mini games, there are also minor interactions that the player has to carry out, which will provide them with related information from the AI home assistant. The player has to push a button to flush the toilet, as well as pick up a cooking pot, and pour its contents into a potted plant.

Specifically, the AI home assistant will talk about water consumption when flushing the toilet and how to save water, as well as the idea of re-using water for e.g. watering plants.

4.7 Implementation of Persuasive Technology

As covered in Section 2.4, persuasive technology would improve the persuasiveness of the game. Therefor a lot of effort has been put into reaching an adequate level of implementation where some of these technologies have the desired effect.

4.7.1 Simulated Environment and Objects

After the initial concept was made, and as suggested by Jerald [2015, pp. 54], it was chosen to keep the game as non-photo realistic in its style, according to the concept about representational and interaction fidelity. All the household objects, and the house itself, are properly proportioned and based on measurements from their real world counterparts. Nothing is left abstract, so the player should be easily capable of identifying what a given object is, as well as how to interact with it. This is further improved by designing the interactions according to how you would normally do the interactions in reality. Some interactions have been simplified a lot in comparison to the very complex real world equivalent. An example is how taking a shower would normally involve soaping in an entire body, not to mention the varying amounts of hair from person to person. This means that a lot of variable factors are not accounted for, but it was assumed that it would not have any significant impact on the experience, nor the message of the game.

4.8 Level Design

In order to get started, an outline was made in blender, which included all the rooms needed to fullfill the purpose of the game. The initial layout didn't change much throughout the implementation process, though the living room was extended in order to fit the couch and not block the projector that shows the player how they fared in the different tasks. In order to make the house a little more believable, an unused bedroom was added, even though it is inaccessible. Figure 4.1 represents a name tagged overview of the entire layout.

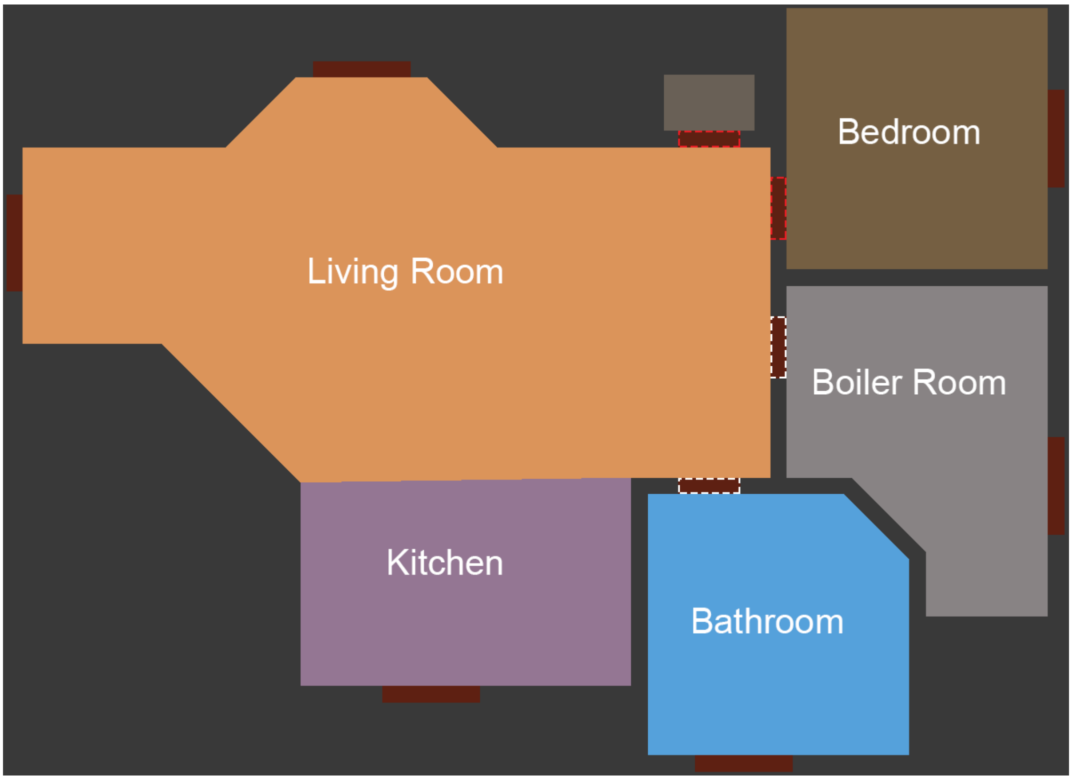

Figure 4.1: A top down, orthographic view of the entire layout of the house.

Once the initial layout was done, the walls were widened so they had some mass to them. The height of the walls was defined through the use of real world measurements. The frame of the house can be seen in Figure 4.2.

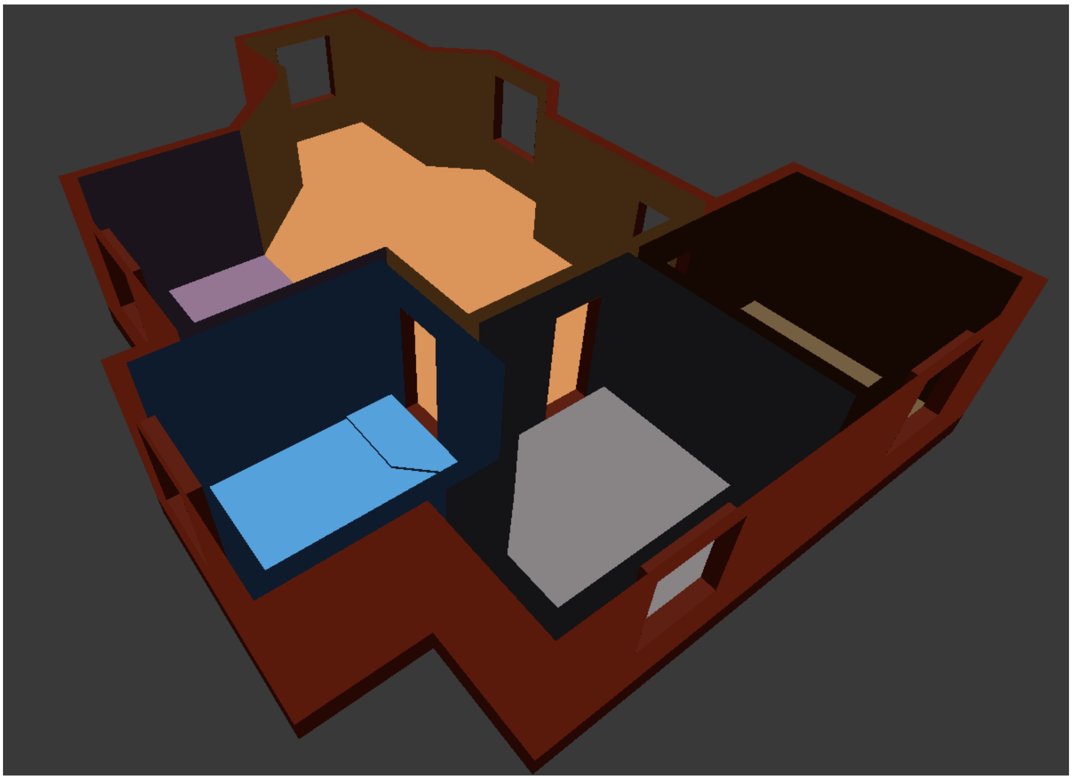

Figure 4.2: An overview of the layout and wall height/thickness.

Because there are no items that clutter up the game space, only items that are usable by the player is present, thus reducing the potential of the player getting confused.

4.8.1 Simulated Cause and Effect Scenarios

It can be argued if simulated cause and effect is truly implemented, but for the minigames, the player is at least capable of seeing how their actions influence their consumption of water, which could be translated to the real world if the player makes such a connection.

4.8.2 Social Actor

As outlined by Jerald [2015, pp. 269] it could be useful to provide feedback through audio in a game, that's why an AI home assistant was designed as the main means of telling the player what to do, and giving feedback whenever a task was completed. The AI is can be considered a social actor, that is almost authoritative in nature in the context of the game. The AI, more or less, dictates what the player has to do next, and keeps them moving forward by reminding them what to do. For prototyping purposes, the AI will be implemented by using Microsofts text to speech feature that is built into windows. Apart from making it easier to make changes to the narration, it also provides a very authentic feel to the AI. Due to the importance of what the AI has to say, it can be argued that it would be wise to implement voice acted narration in order to make the words more clear for future iterations.

4.9 VR Specific Design Considerations

The game was designed to be an enjoyable and rewarding experience Jerald [2015, pp.267]. Because VR can be fatiguing in extended sessions, It was designed to be a short experience that would take no more than 15 to 20 minutes Jerald [2015, pp.217]. In order to accommodate VR better, much of the space inside the house is very large and open. This should make it less possible for the player to accidentally bump into virtual 3d objects such as counters and walls. Through the implementation of properly proportioned models, it should also feel like a more believable experience to navigate around and interact with objects. An attempt was also made to limit the amount of traditional UI elements, by incorporating them into the geometry of the world instead. It does mean that the player cannot see an overview of how well they did in all their tasks, unless they go to the living room, but it is an acceptable compromise. There is a 2D screen, implemented as suggested by Jerald [2015, pp.157], which is projected on the wall, as it is an important to be able to reflect on your own performance as a player Jerald [2015, pp.156].

Other VR specific considerations were done in relation to interactions and controls. Due to the few input methods on the controllers, there is little room to have separate buttons for specific functions. This means that interactions had to both be simplified, but also made sure to not overlap. An example could be whether the player can turn the water on/off while carrying a piece of soap. If the player could not do so, they would have to put down the soap if they wanted to turn the water on or off, leading to a lot of wasted water that is purely due to game logic, not a simulated real world situation. A lot of time and effort was also put into various iterations of the different interactions. Whenever possible, it was desired to make the VR interactions as close to real life, in the hopes that the player would have an easier time to do said interactions [Jerald, 2015, pp.355]. The game was designed to provide useful feedback to the player Jerald [2015, pp.355] when they were doing an action or using an item correctly, through different sensory outputs such as sounds, narration and visuals in the form of particles [Jerald, 2015, pp.356] [Jerald, 2015, pp.156]. The game is designed to be as consistent with its in-game rules as possible, meaning that the controls and core experience of the game should not drastically change between mini-games [Jerald, 2015, pp.156] [Jerald, 2015, pp.268].

A reoccurring concern was whether or not a button press would be required in order to carry out an interaction. Though not consistently implemented this way, it was concluded that button presses seemed to feel appropriate when one wanted to intentionally pick up or drop an item, whereas moving an item and interacting through them should only use a button press if the real life equivalent requires the same. An example of this is the difference between a vacuum cleaner and a mop, where the mop uses hand motion to "activate" it, while the vacuum uses a button press. The player navigates the game by teleporting. The player teleports by pressing the touchpad on the controller, point at the spot they want to go and then release the touchpad. If the player points at an allowed surface, which is indicated with a green marker on the ground, the player will teleport to that position in the virtual world. The surfaces that the player is allowed to teleport to change based on which mini game is currently played. The green markers are also used to guide the player around the house to his next task [Jerald, 2015, pp.269]. The torso of the avatar is invisible, except when it is used for gameplay. This is done to avoid distractions, while performing different tasks.

4.10 Theme, style and location

Various decisions had to be made in terms of the theme, style and location of the VR experience. Although gameplay defines what the player will be doing, the visuals are what the player will be seeing, which makes it equally as important. This does not mean that one needs to always have super realistic visuals, but rather a coherent art style that fits the mood of the game.

In order to accommodate a relaxing setting for the player to explore the narrative and gameplay, a hand painted, toon based style was accomplished within the various household assets and exterior scenery. This made it possible to make a more high-contrast, colourful and vibrant world for the player to explore, compared to the otherwise more low contrast, de-saturated look of a more realistic approach. It also has the added benefit of lower poly count and texture resolution throughout all assets. Another benefit is that of less computationally heavy shaders when it comes to physically based rendering materials. Effects such as highlights and shaders are painted directly into the textures, instead of computing them at run-time, which doesn't work as well for a more realistic approach. Variety of depth cues were included such as shadows to help enhance the presence and the spatial judgments of the player as outlined by [Jerald, 2015, pp.157]. The apartment is divided in distinct zones as suggested by Jerald [2015, pp.270-271], which helps limit the player space for each mini-game and bring different characteristics to each zone.

The location for the game was chosen between either country side, or inside an apartment. The country side approach was chosen due to possibility of having a colourful exterior, and a more relaxing ambience around the player, compared to the hustle and bustle of a city-based apartment. It does come at a performance hit, as swaying trees with transparency can be quite heavy on rendering, though everything was done to try and optimise this feature to reduce lag.

A more in-depth and technical explanation on the visual aspects of the implementation can be seen in Appendix D

4.11 Sound and Music

There are sounds in the game which consist of ambient nature sounds to provide realism and presence Jerald [2015, pp.269]. There is non-diegetic background music that suits the style of the game. All items have sounds that mimic their real life counterparts in order to make the experience more immersive. The sounds are also giving feedback to the player when they are doing an action [Jerald, 2015, pp.269] . The sound levels in the game were adjusted in order to prevent the player from getting overwhelmed by loud sounds [Jerald, 2015, pp.269].

4.12 Preliminary Usability Testing and Iterations

In order to fine-tune the usability of the VR experience, 2 sessions were held at Grundfos, where various people played the game. In general, they would give feedback either while or after playing, pointing out flaws or areas that could do with some improvements. One of them did an impromptu speak aloud test where more in-depth feedback was given, which also lead to further discussions. Apart from the major play sessions with multiple people, the VR experience also went through various iterations based on supervision feedback where the supervisor for the project would play and give feedback while doing so. The feedback can be seen in "Evaluation Data.zip" for the full "Initial Usability Test Data.tsv". Though this was very time consuming, it made the end result a lot more stable, but also the interactions more intuitive.

4.13 Relation to State of the Art

As mentioned in Section 3.7, persuasive technology is indeed possible to implement in a VR experience. Compared to the various state of the art that were investigated, this implementation gives the player a myriad of different interactions to carry out, but is still making sure to keep the player on track, although by limiting the player's actions and the order in which they are done. Since this VR game mostly implements persuasive technology as a media, rather than a tool, it differs a lot from the state of the art which focuses on showing the user what can normally not be seen, because it is hidden away underground or within the human body. The biggest difference is that the values used in the "tools" are physically accurate in order to simulate their real world equivalent, whereas this game settles on using approximations in order to share ideas and concepts in relation to water consumption.

Chapter 5
Evaluation

5.1 Evaluation Plan Overview

The evaluation was carried out in an repeating AB, BA order, where the VR game experience, as well as the conventional material, will be split into 2 equally weighted halves. This means that each test participant played one half of the game, and was exposed to another half of some conventional material. Before and after playing the game, and being exposed to the conventional material, the participants was asked to fill out some questionnaires that provide data that could be subsequently analysed in order to address the problem statement and research questions in Section 4.1.

The conventional material consists of the cape town challenge flyer and one A4 page worth of informational text, which is a collection of information that is based on the various sources that were used in order to design the game.

The alternative would be to have some participants only play the game, while others would only be exposed to the conventional material. The issue with such an approach would be the rise in required test participants, as the data is prone to having a high variance. This is the case due to how the questions are all subjective, and people have different pre-existing knowledge, as well as different understandings on how something like a VR experience should look and feel like in order to be engaging to them, thus creating more variables and conditions that need comparing.

In order to make the evaluation from participant to participant consistent, a procedure was outlined as a guideline for facilitating the evaluation. The full procedure can be seen in Appendix E.

5.2 Preparation

In preparation of the evaluation, a material list was used to make sure that all the required materials etc. were present. Then, the VR equipment would be set up and the game was tested to make sure that everything was working as intended, including a sound check. Before fetching participants, it would be determined which order they would experience, so that the game settings and text material were ready.

5.3 Introduction

The participants would be briefed on the purpose of the evaluation and given a rough time estimate on how long it would take to complete. Once within the evaluation environment, the participant would be introduced to the project group and subsequently to the evaluation procedure itself.

5.4 VR Sickness Evaluation

Since VR sickness can negatively influence the experience, and thereby engagement, participants will be asked to answer a questionnaire with related questions.

If a participant experienced any kind of VR sickness, it will likely influence their other answers made throughout the test. The questionnaire to measure VR sickness is the Simulator Sickness Questionnaire, the questions in the questionnaire can be divided into three subscales measuring nausea, oculomotor and disorientation. By using these three subscales a total score can be calculated [Kennedy, 2001].

The nausea subscale includes the symptoms that relate to nausea, stomach awareness, burping and salivation. The oculomotor subscale is about difficulty in focusing, headache and blurred vision. Disorientation subscale relates to vestibular problems such as vertigo and dizziness. By using these three subscales a total score can be calculated, where the score itself goes to 314 , if each item in the questionnaire is answered as severe.

5.5 System Usability Scale

In order to analyse whether the VR experience provides sufficient feedback, feedforward, and everything else related to usability, a system usability scale (SUS) questionnaire was filled out by the participants. Findings here could provide an indication on whether engagement might have been affected by the usability.

The SUS is reliable tool for measuring usability for a wide range of products and services, the SUS is used often enough to become an industry standard.. The questionnaire consists of 10 item questionnaire with five responses. The benefits of using a SUS is that participants easily understand it. Even with smaller sample pools, the SUS can provides reliable results. And has proven to be able to effectively tell if a system is usable. The best way to analyse the results is by "normalizing" the scores by comparing it to a database in order to produce a percentile rank. The SUS is not diagnostics tool, and is purely used for its ability to classify the usefulness of a system [Affairs, 2013].

5.6 Intrinsic Motivation Inventory

Participants were also asked to fill out an intrinsic motivation inventory (IMI), in order to collect data on how engaged the participants were when playing the game, or being exposed to the conventional material.

The IMI is a measurement tool that assess a participants subjective experience in an activity. The IMI has multiple dimensions such as: interest/enjoyment, competence, effort, value/usefulness, felt pressure and tension and perceived choice. Though the only one that is used for measuring the intrinsic motivation is the interest/enjoyment. The pressure and tension subscale is used as a negative predictor of intrinsic motivation. The value and usefulness subscale shows if the participants thought the system is useful or valuable for a certain purpose [Ryan and Deci, 2000].

5.7 Debrief

As the final step of the evaluation, the participant would be thanked for their participation and offered a cookie or similar as a kind gesture for their participation.

5.8 AB - Order Overview

1. Baseline knowledge evaluation (questionnaire)
2. Play VR game 1st half
3. VR sickness evaluation (questionnaire)
4. Learning outcome evaluation(first half) (questionnaire)
5. Intrinsic Motivation Inventory (questionnaire)
6. System Usability Scale (questionnaire)
7. Get exposed to conventional material 2nd half
8. Learning outcome evaluation(second half) (questionnaire)
9. Intrinsic Motivation Inventory (questionnaire)

5.9 BA - Order Overview

1. Baseline knowledge evaluation (questionnaire)
2. Get exposed to conventional material 1st half
3. Learning outcome evaluation(First half) (questionnaire)
4. Intrinsic Motivation Inventory (questionnaire)
5. Play VR game 2nd half
6. VR sickness evaluation (questionnaire)
7. Learning outcome evaluation(Second half) (questionnaire)
8. Intrinsic Motivation Inventory (questionnaire)
9. System Usability Scale (questionnaire)

Chapter 6

Results

In this chapter, the different results of the evaluation will be analysed. Due to the size of the collected data files, the full data sets can be found in "Evaluation Data.zip" for the full "VR First Test Data.tsv" and "Traditional Material First Data.tsv".

The test consisted of 30 participants (5 females and 25 males). With an age between 21 and 30 years old. Each participant either played Order AB or Order BA , as outlined in Section 5.8 and 5.9.

6.1 Awareness Comparison Between VR and Baseline

As an initial indicator, the awareness results were compared directly to the baseline, which would show an indication on whether participants learned anything in the first place, before analysing further.

6.1.1 Hypothesis

H_A: *The VR experience improves the participants awareness about water consumption, after experiencing VR, compared to their baseline.*

H_{null}: *The VR experience does not improve the participants awareness about water consumption, after experiencing VR, compared to their baseline.*

Table 6.1 shows a summary of the data from the two VR experience halves and the related baseline data.

	Min.	1st. Qu.	Median	Mean	3rd Qu.	Max
Baseline 1	0.0	0.0	0.0	0.4667	0.5	3.0
VR 1	1.0	2.0	2.0	2.333	3.0	3.0
Baseline 2	0.0	0.5	2.0	1.533	2.5	3.0
VR 2	3.0	4.0	5.0	4.6	5.5	6.0

Table 6.1: Shows a summary of the awareness questionnaire, based on how many questions a participant answered correctly

In order to show if there is a significant difference between the participants awareness of water consumption before and after the vr experience, the baseline data is compared with the related vr data, with a Wilcoxon signed-rank test.
Table 6.2 shows the results from conducting a Wilcoxon signed rank test with continuity correction

Wilcoxon signed rank test with continuity correction		
Hypothesis	Mean Difference	P-value
VR 1 Score >Baseline 1 Score	1,8333	0.0007164
VR 2 Score >Baseline 2 Score	3,067	0.00048

Table 6.2: Awareness comparison between the VR experiences and baseline.

6.1.2 Analysis of Awareness Compared to Baseline Result

The Wilcoxon signed rank test shows that both parts of the vr experience improve the participant's awareness of water consumption. With p-values below 0.05, it shows a significant difference in both cases, so it is possible to reject the null hypothesis.

6.2 Awareness Comparison Between VR and Traditional

The awareness related questions were added in order to evaluate whether participants became more aware after playing the VR experience or reading the traditional material. The questionnaire consists of a baseline questionnaire containing 11 questions, which all participants answer, a questionnaire with the first section of questions from the baseline questionnaire, and a questionnaire with the questions from the second part of the baseline questionnaire.

6.2.1 Hypothesis

H_A: *The VR experience is superior in spreading awareness of water consumption compared to the traditional text material.*

H_{null}: *The VR experience is not superior in spreading awareness about water consumption compared to the traditional text material.*

6.2.2 Data Preparation

The first part of analysing the data, is figuring out if people answered the questions correct or wrong. The material was evaluated based on the given answers in relation to the information provided through either the VR game or the traditional material. Correct answers were weighted with a value of 1, and wrong or don't know answers were weighted with a value of 0.

6.2.3 Improvement

In order to see if the participants' awareness of water consumption had changed, the answers from part 1 and 2 were compared to the baseline questions.

The score from the baseline questionnaire is subtracted from their representative parts in the follow-up questionnaires, illustrated in the figure below, whereas the sum of all the questions was calculated afterwards.

This provides four scores: VR part 1 score, VR part 2 score, traditional material part 1 score and traditional material part 2 score. This is done for each participant, which gives each part 15 scores. The initial test conducted then compares the VR part 1 score with Traditional material part 1 score and VR part 2 score with traditional material part 2 score. The comparison is done with the Mann-Whitney-Wilcoxon test.

6.2.4 Awareness Results

The change in score, the raw score and the baseline score can be seen in the Table 6.3.

	Order A		Order B	
	VR 1	Traditional 2	Traditional 1	VR 2
Raw Score	35	65	40	69
Baseline	7	27	10	23
Improvement	28	38	30	46

Table 6.3: A table containing the baseline score, the related experience raw score and awareness improvement score.

In the comparison between VR part 1 and Traditional part 1, the Mann-Whitney-Wilcoxon tests produced the results seen in Table 6.4.

Wilcoxon rank sum test with continuity correction.		
Hypothesis	Mean Difference	P-value
VR 1 Improvement >Traditional 1 Improvement	-0,13	0.6042

Table 6.4: Test whether the improvement from the first part of the VR experience is larger than the improvement from the first part of the text material.

In the comparison between VR part 2 and Traditional part 2, the Mann-Whitney-Wilcoxon tests produced the results seen in Table 6.5.

Wilcoxon rank sum test with continuity correction.		
Hypothesis	Mean Difference	P-value
VR 2 Improvement >Traditional 2 Improvement	2,53	0.1211

Table 6.5: Test whether the improvement from the second part of the VR experience is larger than the improvement from the second part of the text material.

6.2.5 Analysis of Awareness Result

The initial analysis of change in awareness remains inconclusive in order to determine whether the VR experience is better at increasing awareness than the traditional material. The comparison between VR part 1 and traditional part 1 resulted in close to similar results, as revealed by the mean values (28,30), which resulted in a p-value = 0.6. Comparing the results from the second part of the experience showed bigger difference between the VR experience and the traditional material. The mean value from VR part 2 were 46 against and a mean improvement from the traditional material at 38. The confidence value p at 0.12, was not less than 0.05, and therefore the difference was insignificant in both cases.

6.2.6 Shortcoming of Method

There are a few shortcomings when using the previously described method. If a participant manages to answer all questions correctly in the baseline questionnaire, it would be impossible to score any points in the following questionnaires. Another shortcoming is that an uncertain amount of bias is introduced, when the open questions were evaluated to be either right or wrong.

6.3 Intrinsic Motivation Inventory

The questionnaire uses three subsections for the IMI, namely: Enjoyment/Interest, Usefulness/Value and Pressure/Tension. Each subsection describe different aspects of intrinsic motivation and therefore a score for each subsection needs to be calculated, which required each subsection to have its own hypotheses to be analysed.

6.3.1 Hypotheses

H_A: *The VR experience is more enjoyable and interesting than the reading material.*

H_{null}: *The VR experience is not more enjoyable and interesting than the reading material.*

H_A: *The VR experience is more useful and enjoyable than the reading material.*

H_{null}: *The VR experience is not more enjoyable and interesting than the reading material.*

H_A: *The traditional material makes the participants feel more pressure and tension than the VR experience.*

H_{null}: *The traditional material don't make the participants feel more pressure and tension than the VR experience.*

6.3.2 Data Preparation

In the IMI, certain items are reversed, so in order to find the actual score for those items, the score need to be reversed as well. In the case of a 7-point-likert-scale, it is done by subtracting the item score from 8.

6.3.3 IMI Results

The results of a subscale is calculated by taking the average score of all items in the subscale. Table 6.6 shows the average score for each part of the experiment.

	VR 1	VR 2	VR Total	Traditional 1	Traditional 2	Traditional Total
Enjoyment/Interest	5.52	5.54	5.53	3.68	3.55	3.61
Pressure/Tension	2.53	2.17	2.35	1.92	1.82	1.87
Usefulness/Value	4.86	5.30	5.08	5.28	4.79	5.03

Table 6.6: Average scores for the various IMI subscales for each part of the experiment.

As seen in Table 6.7, the participants' pressure and tension, during the VR experience, are above the scores from the traditional material, however it is still below 4, and therefore in the low end of the scale. In order to see if the values are significantly beneath 4, two one sample t-tests are carried out.

Wilcoxon signed rank test		
Hypothesis	Mean	P-value
VR part 1: Pressure/Tension Score <4	2.53	0.0006482
VR part 2: Pressure/Tension Score <4	2.17	0.0004484

Table 6.7: Table showing the results from evaluating whether the pressure and tension that was reported is significantly lower than 4.

As seen in Table6.7, both pressure/tensions scores are significantly lower than 4, since the p-value are less than 0.05, with a mean value 2.53 and 2.16.

In order to see if there is a significant difference between the different parts of the experience, a Wilcoxon signed-rank test is used to compare VR1 with Traditional 2 and VR 2 with Traditional 1, and VR total with Traditional total. The results can be seen in Table 6.8.

Wilcoxon signed rank test with continuity correction		
Hypothesis	Mean Difference	P-value
VR2 Interest >Traditional 1 Interest	1.87	0.0003606
VR2 Pressure >Traditional1 Pressure	0.24	0.3246
VR2 Value >Traditional 1 Value	0.02	0.7747
VR 1 Interest >Traditional 2 Interest	1.97	0.003484
VR 1 Pressure >Traditional 2 Pressure	0.72	0.01176
VR 1 Value>Traditional 2 Value	0.07	0.5157

Table 6.8: Per individual comparison of participants' VR IMI scores with their text material IMI scores

Lastly, the first part of the VR experience was compared to the first part traditional material and second part of the VR experience was compared to the second part of the traditional material, the results can be seen in Table 6.9.

Wilcoxon signed rank test		
Hypothesis	Mean Difference	P-value
VR 1 Enjoyment >TM 1 Enjoyment	1.85	0.001203
VR 1 Pressure >TM 1 Pressure	0.61	0.07288
VR 1 Value >TM 1 Value	-0.42	0.8201
VR 2 Enjoyment >TM 2 Enjoyment	1.99	0.0009854
VR 2 Pressure >TM 2 Pressure	0.35	0.3283
VR 2 Value >TM 2 Value	0.50	0.2087

Table 6.9: Compares VR part 1 IMI scores with the text materials IMI scores , and VR part 2 IMI scores with text material 2 IMI scores

6.3.4 Analysis of IMI Results

As there are three IMI subscales that were evaluated, their analysis will be split up equivalently.

Enjoyment

The test regarding enjoyment shows that the majority of test participants reported higher enjoyment during the VR experience. This was also confirmed by the different tests when comparing the VR enjoyment to the traditional enjoyment results. The analysis used 4 different comparisons between different parts of the VR experience against the traditional material, in all cases the VR experience was significantly better, as seen in the p-values.

Pressure

The VR experience got slightly higher scores regarding the pressure and tension that the participant felt. In 1 out of the 4 tests, the participants felt significantly higher pressure and tension in the VR experience, when compared to the traditional material. In the remaining three tests, the participants still felt more pressure and tension, however, the results were insignificant, as the p-value was above 0.05.

Value

The results of the value part of the IMI remains without conclusion whether one part is superior to the other. None of the 4 tests had a significant difference in either direction, thus making the perception of usefulness similar for both experiences.

6.4 System Usability Scale

The SUS can be used to evaluate a system, and is also useful for evaluating whether there are issues in the system that need to be addressed. The SUS results are then computed in order to obtain a system score that can be used to compare the system against other similar systems.

6.4.1 Hypotheses

H_A: *The current usability score of the VR experience is above the average score on the SUS.*

H_{null}: *The current usability score of the VR experience is not above the average score on the SUS.*

6.4.2 Data Preparation

In order to evaluate the system score, the data needs to processed. Odd questions are positive loaded questions, whereas even questions are negatively loaded questions. With all odd questions, one needs to subtract 1 from the score, with all even question, one needs to subtract the score from 5. The end result is a score from 0-4 for each question.

6.4.3 Calculating the System Score

After the initial data preparation, one finds the sum of all the items, then multiplies it with 2.5, which gives the following formula: System_Score = sum(items) * 2.5. This gives a score between 0 and 100. Table 6.10, shows the calculated system score for VR part 1, 2 and the whole experience. It is a given, that it is the mean values between all test participants.

The three obtained SUS scores are then compared to the Sauro database by using the conversion guidelines found in the book: Quantifying the User Experience: Practical Statistics for User Research [Sauro and R. Lewis, 2012], which gave the percentile rankings and a system grade seen in Table 6.10.

	VR part 1	VR part 2	VR Experience
Score	73.83	71.83	72.83
Percentiles	70% (67% - 70%)	63% (60–64)	70% (67% - 70%)
Grade	B-	C+	B-

Table 6.10: Calculated system usablity score, percentile and grade.

As seen from the Table 6.10 the score for the VR part 1 is 73.83 and for the VR part 2 is 71.83 on the system usability scale.

6.4.4 Analysis of the SUS Results

The different parts of the SUS shows that the VR experience is slightly above average in terms of usability, when comparing the SUS score to the Sauro database and converting it to a percentile score. The overall grade for the experience is between C+ and B-.

6.5 Simulator Sickness Questionnaire

The simulator sickness questionnaire is used to identify whether certain participants felt some form of discomfort doing the VR experience. It also shows if the system in general has a tendency to cause discomfort for test participants.

6.5.1 Hypotheses

H_A: *Participants will not feel a significant amount of VR sickness*

H_{null}: *Participants did feel some form of VR sickness.*

6.5.2 Data Preparation

The first step is to convert the text into numbers from 0-3, where 0 = none and 3 = severe, these numbers are then used to calculate three subscale scores and a total system score.

6.5.3 SSQ Results

The SSQ contains three subscales, nausea, oculomotor and disorientation. Each item in the questionnaire influences one or more of the three subscales. In order to find the score of a subscale, one calculates the sum of each item that influence the given subscale. When one has all the result of each subscale, they can be used to calculate a total score by multiplying the sum of the three subscales with 3.74. A table containing the various scores can be seen in Table 6.11.

	Nausea	Oculomotor	Disorientation	Total score Median	Total score Average
VR 1	1,53	2,2	1,53	14.96	19,69
VR 2	0,66	1,2	0,8	3.74	9,97

Table 6.11: The results for the SSQ subscales.

In order to get an idea of how severe symptoms the VR experience induces in people, the results are compared to 6 categories that NASA defined [Kennedy, 2001] in relation to the SSQ questionnaire as seen in Table 6.12.

Score	Categorization	Participants (VR 1)	Participants (VR 2)	Participants (total)
0	No Symptoms	0	5	5
>5	Negligible Symptoms	2	3	5
5-10	Minimal Symptoms	1	2	3
10-15	Significant Symptoms	6	2	8
15-20	Symptoms are a concern	0	1	1
>20	A problem simulator	6	2	8

Table 6.12: The table shows the distribution of participants across the two halves of the VR experience, in relation to their SSQ scores.

By comparing the simulation sickness scores to the categories, it is shown that 6 participants from Order A have a score above 15, which suggest they had concerning symptoms. In Order B, only 3 participants had a score above 15. A plot of the SSQ scores can be seen in Figure 6.1.

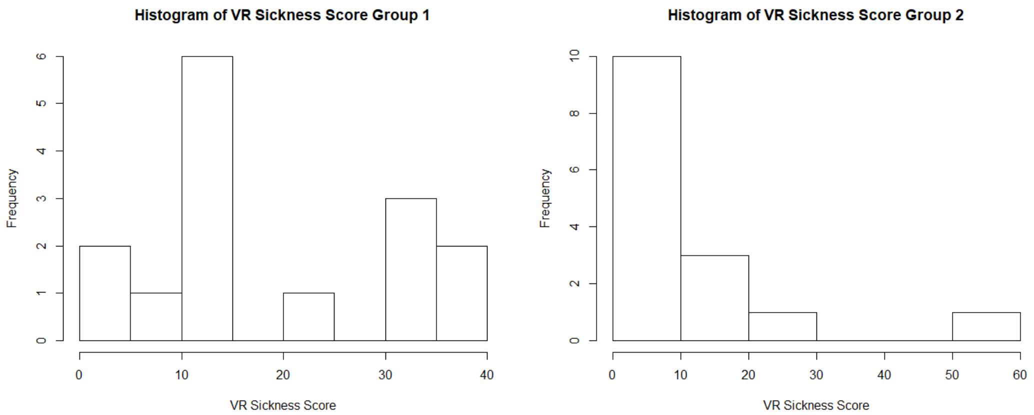

Figure 6.1: Left histogram shows participants playing the first part of the VR experience and the Right histogram shows participants playing the second part of the VR experience. The Y axis shows the frequency of a certain score and the x axis shows the total SSQ score.

As seen in figure SSQ_Scores, the participants playing the second part of the experience had lower scores than the participants playing the first part. The results show how only two participant in the first group had a lower SSQ score than 5, whereas eight participants from the seconds group had a lower score than 5. The table and image also shows that there are more people playing the first part of the experience with with ssq scores > 20, than people from the second part of the vr experience.

6.5.4 Analysis of SSQ Results

The results of the SSQ shows that some participants had issues regarding the vr experience, when their scores are compared to the categories made by NASA. The histograms also shows that the main part of the participants has a score < 15, whereas some participants had very high scores.

6.6 Further Analysis

After initial analysis of the results were completed, a few alternative angles were used to look at the data.

6.6.1 Awareness

To further analyse the results for awareness, two other methods were used.

1. Calculate each participants improvement for VR and Traditional material, and subtract the traditional materials score from the VR Score.
   (a) VR_Superioriy = VR_Improvement - Traditional_Improvement
2. Second method was to use the VR sickness score to filter out people with high VR sickness score, from the datasets.

6.6.2 VR Superiority Test

As with the previous analyses, the same method for investigating potential improvement was used, meaning: improvement = after exposure - baseline. Each participants traditional material improvement score, is thus subtracted from their VR improvement score, which results in one set of 30 integers, instead of having two sets of 15 integers. The difference in approach is that VR and traditional results are compared to 0, rather than the previous method which compared VR and traditional to each other directly. A histogram of the result can be seen in Figure 6.2.

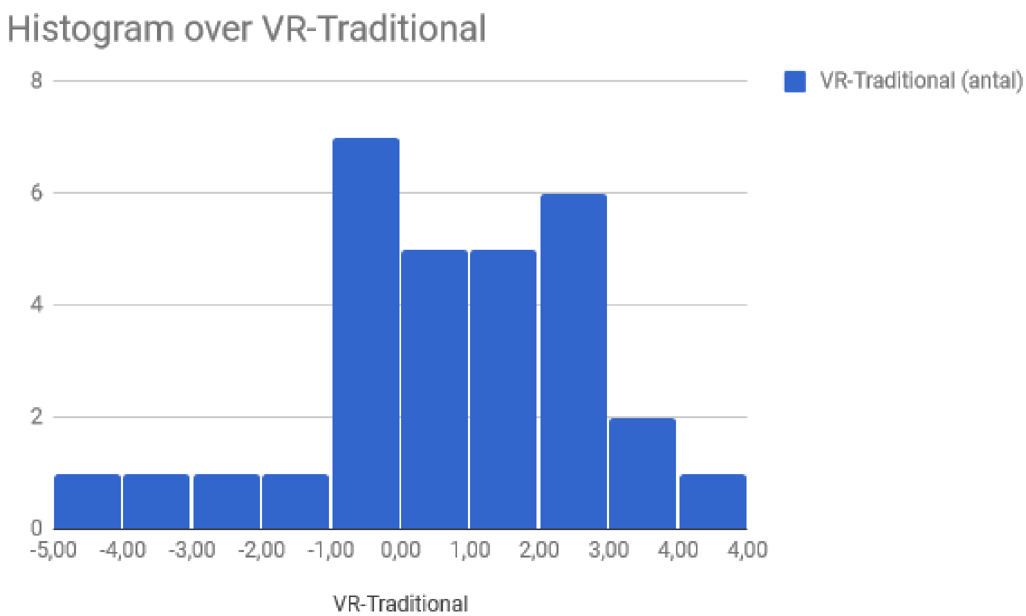

Figure 6.2: Histogram showing the result of subtracting each participants' traditional score from their VR score.

As seen in Table 6.13, the values go from -5 to 4, where negatives scores represent people who improved most from the traditional material, and positive scores represent people who improved the most from the VR experience.

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	variance	standard deviation
-5.0	-1.0	0.0	0.2	2.0	4.0	4.234483	2.06

Table 6.13: Data summary of the 30 participants traditional score subtracted from their vr score

The mean value is above 0, meaning that the average user improved more when using the VR experience compared to the traditional material. In order to see if the result is significant, a Wilcoxon signed rank test is used, the result can be seen in Table 6.14, which can also be used to address the previously mentioned hypothesis in Subsection 6.2.1.

Wilcoxon signed rank test		
Hypothesis	Mean	P-value
(VR improvement - Traditional improvement) >0	0.2	0.1946

Table 6.14: traditional score subtracted from their VR score compared to 0 with a Wilcoxon signed rank test

It is still not possible to reject the null hypothesis, as the p-value is not less than 0.05 and therefore the difference is insignificant.

6.6.3 Analysis of VR Superiority Test

The results still don't show a significant difference between the learning outcome from the VR experience and the text material. The histogram from Table 6.2, shows that many participants learned equally much from the VR experience and the text material, with a small lead to the VR experience.

6.6.4 SSQ Filter for Awareness Evaluation

It is hypothesised that one of the main issues that could affect the learning outcome of the VR experience negatively is VR sickness.

> H_A: *People with low SSQ score will have higher improvement related to the VR experience than people with high SSQ score.*
>
> H_{null}: *People with low SSQ score will not have higher improvement related to the VR experience than people with high SSQ score.*

Therefore, an awareness evaluation was done to see if the VR sickness score affected the learning outcome. In Table 6.15, it is shown how different vr sickness score filters alter the mean learning outcome of the vr experience.

VR Sickness Score Threshold	VR P1 Mean Score	VR P2 Mean Score
20	2.076923	3.333333
15	2.25	3.333333
10	2.2	3.666667

Table 6.15: A table showing the learning outcome for particpants filtered by their SSQ score.

In addition Figure 6.3 shows the VR improvement scores compared to the VR sickness scores.

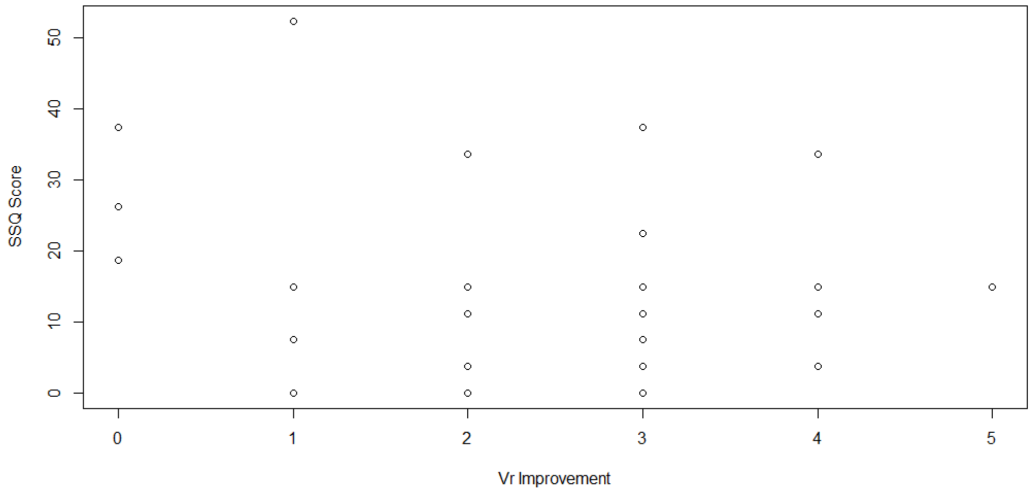

Figure 6.3: The figure shows the VR awareness improvement on the x axis and the related SSQ total score on the y axis.

In order to check if there is any significant difference between the amount that people learn by playing the vr experience, both orders are sorted based on their vr sickness score and split into two, meaning four groups: two with participants with the lowest vr sickness score and two with the participant with high vr sickness score. Table 6.16 shows the results.

Wilcoxon rank sum test with continuity correction		
Hypothesis	Mean Difference	P-value
VR score for people with low SSQ >VR score with high SSQ score VR experience part 1	0.8571429	0.1032
VR score for people with low SSQ >VR score with high SSQ score VR experience part 2	0	0.5787
VR score for people with low SSQ >VR score with high SSQ score VR experience whole	0.2666667	0.3748

Table 6.16: Tests that compares people with low SSQ scores, with people that have high SSQ scores, in relation to their learning outcome.

None of the three experiences report any significant difference, so it remains inconclusive whether or not the SSQ scores had an effect on the amount that people improved their awareness by playing the VR experience, since all three tests fail to reject the null hypothesis.

The filtered data can be compared to scores from the traditional material, to see if the filtered data would produce significantly better scores than the traditional material, when it comes to creating awareness about water consumption.

H_A: *People with low ssq score will show more improvement than people that reads the traditional material.*

H_{null}: *People with low ssq score will not show more improvement than people that reads the traditional material.*

The evaluation results addressing the hypothesis can be seen in Table 6.17.

Wilcoxon rank sum test with continuity correction		
Hypothesis	Mean Difference	P-value
Filtered VR 1 Improvement >Traditional 1 Improvement	0.2857143	0.2446
Filtered VR 2 Improvement >Traditional 2 Improvement	0.4666667	0.2131

Table 6.17: Comparing the learning outcome for people with low SSQ score, with the related text material.

6.6.5 Analysis of Awareness When Filtering Based on SSQ Results

The results show a small tendency between the vr sickness score and the learning outcome from the vr experience. However, none of the initial tests show a strong enough correlation to make the difference significant, and therefore fail to reject the null hypotheses. The filtered VR data also shows a tendency to improve awareness of water consumption, however the results are still not significant with p-values > 0.05.

6.7 Post Test Questionnaire

The questionnaire looks into, what part of the experience the test participants preferred and if they had any feedback regarding the experience, where 24 out of the 30 participants answered it.

6.7.1 Hypothesis

H_A: *Participants prefer the virtual reality experience over the traditional material.*

H_{null}: *Participants did not prefer the virtual reality experience over the traditional material.*

6.7.2 Preference Results

The questionnaire shows that 75% of the participants prefer the virtual reality experience over the traditional text material and 25% of the participants prefer the latter. An exact binomial test was used to evaluate the hypothesis, with the results visible in Table 6.18. For the full data set, check "Evaluation Data.zip" for the full "Additional Qualitative Data.tsv".

Exact Binomial test			
Hypothesis	Number of trials	Success	p-value
People prefer the VR experience >People prefer text material	24	18	0.01133

Table 6.18: Table showing a summary of the exact binomial test, regarding the participants' preference.

The exact binomial test shows that there is a significant difference in the preference of the participants, meaning that the null hypothesis can be refuted.

Chapter 7
Discussion

There are various points to be made in regards to the results that were gathered through the evaluation process. Therefore it will be discussed how various factors of the evaluation and game could have affected the results, in an attempt to add plausible explanations to the numbers that were outlined in Chapter 6.

7.1 Discussion of Result Analyses

Based on the results outlined in the various analysis sections within Chapter 6, combined with the theory covered in Chapter 2, there are some plausible explanations as to the reason for the outcome.

Specifically, when investigating existing use of VR for teaching purposes, it was mentioned in Section 2.1, that the learning outcome tended to show varying results, also noting that VR performed equally well as traditional textbooks in one comparison. These statements correspond with Subsection 6.2.5, which showed no conclusive indication that VR would be better than traditional material in regards to spreading awareness.

It can be argued that some of the knowledge was unevenly represented within the VR experience, thus making some concepts easier to grasp than others. It is important to note that the findings in relation to knowledge is only in regards to short term effect. As long term knowledge retention was not investigated, it is currently not possible to make any conclusions, on whether the VR experience has a higher impact on the participants, due to the various modalities that VR has compared to a piece of paper. Furthermore, it could also be of interest to investigate any effects that the experiences might have on participants' behavior.

With that said, it does not mean that the VR experience failed to spread awareness, as Subsection 6.1.2 shows that there was a significant increase in awareness when comparing the VR experience to its baseline.

The results from IMI in Section 6.3.4, show that people found the VR experience more interesting and enjoyable than the traditional text material. There were also some indications towards that people felt more pressure and tension while trying the vr experience, compared to the traditional text material, however, it was only significant in 1 out of 4 tests. It is also notable that both pressure/tension mean values are below 4, which indicates that people didn't feel pressured in either experience. The value and usefulness comparison didn't show any conclusive result in favor of either the VR experience or the traditional text material. Both experiences received a score above 4, which could indicate they each had some form of value.

Because participants didn't feel pressure or tension when playing VR, there is a good indication that they were immersed to a degree that made them focus on the experience and forget the real world to some degree.

The follow-up questionnaire confirms that people prefered the VR experience over the text material, with 75% of the participants preferring the VR experience and 25% of the participants preferring the text material.

Another factor that would influence immersion, is how some participants got distracted enough, so that they didn't pay attention to the AI. The 1 minute cooldown before the AI would repeat its sentence, might be too long, as the players also started to get frustrated, often asking facilitators for help and/or taking of the HMD. The distractions could have been caused by not having any warm up section for the VR experience, instead throwing the participant straight into an AI that starts talking to them before they get their bearings.

In regards to system usability, Subsection 6.4.4 shows that the VR experience ranks as above average, with a classification between C+ and B-. For a prototype, an above average score might be sufficient. It can be debated whether the seemingly "un-intuitive" controls, at times, are just a bi-product of there being various conventions for VR controls, not to mention that it might not be expected by the participants, that interactions are one-to-one, when compared to the real world equivalent. An example would be how players don't use their whole arm to rotate the wrench properly, but rather rotate it like a screwdriver, or don't rotate it at all. Some even tried to move the whole wrench in a circular pattern around the bolts, instead of rotating it. This might indicate that it would be useful to investigate how players approach supposedly simple interactions with objects of a real world nature, a simple example could be for the participants to speak aloud as to how they expect an interaction to work, both before and after trying it out.

In order to account for participants whose experience might have been affected by VR sickness, their answers from the SSQ were analysed, which in Subsection 6.5.4, indicated that a few participants had severe, critical or problematic VR sickness symptoms, compared to the categories provided by NASA. It is important to note that the SSQ is compared to a database that likely reflects NASA's potentially high standards.

Unfortunately, filtering out participants according to the SSQ results, as shown in Subsection 6.6.5, showed no significant difference between the filtered and non-filtered datasets, in terms of gaining awareness.

One known issue with the VR experience, is that the frames per second (FPS) can fluctuate based on where the player is looking. This can be blamed on either insufficient optimisation in the game, or a graphics card that was unable to handle the graphically expensive process of rendering the scene multiple times for it to work within the HMD.

Furthermore, some VR discomfort could be explained by improper calibration of the HTC Vive, or the use of earplugs over headphones in some instances. These potential issues could likely have been prevented by being more consistent with the hardware used for the evaluation, as well as being more thorough when preparing the participant for the VR experience. Naturally, this would make the evaluation take a lot longer, time that the participant might not be willing to set aside when considering the already time consuming questionnaires.

Chapter 8
Conclusion

The main purpose of this conclusion is to address the problem statement from Section 4.1, namely:

> "How does a VR experience, using persuasive technology, fare against more traditional material, in terms of its effect on spreading awareness regarding water consumption."

Furthermore, the conclusion will take the points made in Chapter 7 into account, which is based on the results that are outlined throughout Chapter 6.

It can be concluded, that the VR experience can improve people's awareness of water consumption, however it does not outperform comparable text material in any noticeable way.

The VR experience turned out to be more enjoyable for the participants, which was seen in both the preference question and the IMI subscale interest/enjoyment evaluation.

It remains inconclusive whether the VR experience puts more pressure and/or tension on the participants and whether the vr experience is more valuable and/or useful than the text material.

The VR experience performed decently regarding usability, with a percentile score slightly above average. However, the VR experience did in some cases inflict some form of VR sickness on the participants, whether this influenced the results remains inconclusive.

Chapter 9
Acknowledgement

We would like to thank Grundfos for the amazing opportunity to collaborate and give us free reign to explore the possibilities for the project. The added help with water related background research made the process a lot smoother, and has hopefully resulted in a prototype that is satisfactory. Also, providing VR equipment and a computer to the project was highly appreciated as it made the development and evaluation of the VR experience less stressful.

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Appendix A
Water Quality and Availability Interview Transcript

The interview took place at Grundfos' headquarters in Bjerringbro on the 14-03-2018. The main participants were: Christian Schou(CH), Lasse Chor(LA) and Thorsten B. Nielsen(TH). The purpose of the interview was to get an idea on how to define water quality and availability, and how it could relate to a VR game by establishing potential problem areas.

CH: I actually have a Grundfos angle on what you are trying to do that is extremely relevant right now, that was just promoted by Mads Nipper. In SA,I think the first thing that two initial things you should consider.

One thing is, there is a reason, why we don't talk about water purity, but we talk about water quality. Because a lot people have the conception that water quality is about having pure water, but that is not the case. Water quality is about having fulfilled certain standards that we have defined. And measure water, you can estimate the level of pollution, the accepted level of pollution, and that is water quality and not water purity. When we drink tap water, it doesn't mean it is bacteria free, there is around 50000 bacteria pr. Millilitre, but we know they are there, we know which kind they are, and we know that is safe to drink, that is water quality, that is about knowing and not about being pure.

That is very important to get that concept out there, that is really the travel you are on, when you go out to find new water, that is to define a quality are we able to produce it or deliver it and can we use it for that after, and what is the cost for producing that quality, that's really a key issue, when you are talking water quality. Instead of talking about water purity, it is about quality and can the quality be obtained, technological, economically and can it actually be applied to, what we need it for, that's really key in understanding water quality.

TH: What is the difference between water quality and water purity? What is water purity exactly?

Ch: I mean if pure water, I am a biologist, so if I was to say pure water, it would only be H2O right? There would be nothing in it except H2O.

TH: No salt and Minerals.

CH: No, nothing and you couldn't drink it, we couldn't live from it, we would die from emotional stress by drinking that. When we produce our own water, reversive moterbording it is actually so clean, that we have to re-mineralise them to have to make them tasty, we have to add a bit of chlor to be sure that bacteria don't invade and so on. So this is a very important gap between water purity and water quality.

So when you do this walk outside world to find new sources, you really have to consider quality instead of purity. Pure water is not the same as, I mean imagine that you were to have, we have pure water affected with bacteria, it has no bacteria, but what about the (virus) and vira in general, that is actually the thing causing diseases, all diseases around the world is vira in water, should they be there and none bacterial water, could only add something that kill bacteria, then we have home-free pure water-wise on bacteria but not on vira, so it is really really important to define, what do you mean by water quality, we focus on these 5,7,10, whatever, that is really important.

The other thing is that when you consider water scarcity, and you use the term water scarcity, that is actually a mass balance, it is not about having no water or water or the water needed. It is about we have a water need and we have a water source and there is a balance to it. If we don't have enough to meet the old claims, there is two way to fixing it, we can produce more water or we can use less.

And that is actually what the challenge is focusing on right now, that it might not be the best way to produce more water or find more water it is actually more relevant to use less. Because that's less expensive, so balance water and getting water is always about what is the cost of it, and it is much much cheaper to use less water, than to obtain new water.

TH: It also sounds very related to the whole, I can't remember where heard that, but they have to drill deeper and deeper in order to get water.

CH: Yes exactly, exactly. Obtaining new water is always relevant, but would be much much better to use less. I mean in every modern facility have to consider sanitation and you could when you don't define them as the same amount of energy and the same amount of water.

CH: You minimize water, and electric cost, and that is the develop you want and this is cheaper for the end user.

LA: But that is super interesting for the minigames

CH: Yeah exactly. And actually it is a funny game and could you do that, that would be just fantastic.

Because right now the case is South Africa, that they they are struck by scarcity, water scarcity, and has been legislated and they are not allowed to use more than 50 liters of water per day per person, and that might seem amm.... That might seem a lot. Do you know how much we use in Denmark? Shower is roughly 50-70 liters if you are pay. A young teenager would use hot shower 20 minutes will be around 100 liters. But but roughly a normal person we live in Denmark is 120 in Denmark liters per day.

In South Africa as it is warmer and they do more aggregation they do.., sorry, irrigation they actually use 250 liters per day so it is a massive impact on their… on their way of living. But it but it is actually that agenda will have hit a lot of people around the world for the next 10 years. It's hitting in San Francisco and in California are hit big time. They have no water, there is no water running down the mountain due to climate changes.

In big cities around the world they live so many people, they cannot simply transport water into the city..

So and and, what what Grundfos has done to support this agenda is that they made small game: Who are ready to take that challenge within Grundfos. And it could be extremely interesting to have an AI or Virtual reality experience going this is, now you go in see what you normally do but now you have to do it like this what is the consequences for you. That could be really... Mads Nipper, he will love it.

LA: But but actually that is not necessarily too far away from what. Christian: It's it's No no it's the same right because what is what is this new water balance. Can you express that in, now suddenly the toilet is not a flushing toilet, it is an electric toilet or as in aeroplane or is the shower turns off automatically while you are soaked in or whatever, you have been here too long. You used to have a shower in 7 minutes, now you have only 2 minutes. How do you do it? I mean it it open up many many possibilities. Now now you can use only 1 liter for cooking how will you actually do it. There is an alarm going off- BING you are out of water you cannot boil your potatoes. And they have the numbers they have the numbers they used to do, and the numbers they do. It is called the South African challenge. It could be really funny to make this virtual reality how does actually hit someone who is used to 120 liters a day and how is ahh.. How will then do when you only have 50 liters a day

TH: So basically if we get the resources and don't accomplish the task it will basically be failure.

CH: Yes, yes. Or you can go out, you can maybe can be new ideas build

LA: But but what I liked about that approach is the thing we talked about is the awareness just the fact that we are sitting here 4 people not knowing how much water we actually spend when asked the question. And I I...

CH: And I seem to know that it will be world famous that animation after is being published.

LA: The fact that no one knows that, like ..

CH: I have been thinking how does he live right?

LA: Yeah, exactly.

CH: Now you cooked a nice dinner for 10 liters of water. Now you cannot flush the toilet.

CH: I am used to 250 liters, on Denmark 120 liters per day what actually is the difference, what, how how come that the Danish household only use 120 liter, and the American 250 liters per person. It's because the toilets is old, because the plumbing pipes are bigger so more water comes out of the tap, that means one minute gives 4 times the amount of water running into the sewer. And so on and so forth. These little things. If you wash your potatoes how much water you use.

TH: I know a life hack, that you put a coca-cola bottle of water in the reservoir toilet, so that it limits the amount of water.

CH: Yeah, exactly exactly.

CH: Stuff like that, virtualize these ideas.

CH: In Africa, in rural Africa there was an actual, maybe you can look that in there was on Danish television 3. It was thursday or wednesday night at 8, there was an hour about new water projects around the world. And what a lot of them focused in rural areas is that they actually tell and show that that transportation of water that's actually that's actually is such a big time consumer that it eliminates all of cities. Because typically in a typical there is a woman in the house, she uses up to 6 hours to get water, clean water. Walking out there picking a bottle going back making breakfast. Then is lunch, going out there going back and so on. So this time consuming, the idea going out and getting water, that might not be modern or a good idea.

TH: No.

CH: But think there are other ways you can get water. You can do installation of rainwater harvest or reuse of water. The water that has been used in the shower going into the toilet. You should think that way instead of going out and getting it.

TH: Well of course going out is not going to represent realistically in the sense it will take actually 6 hours, but but on the way there you might have the alternative solutions. That might be more viable in the future, requiring you to do something before you get access to it from one way or another.

LA But I guess is asked another question that is assuming we can get back to a point where we can get more water. Which will be interesting just to say that that simply won't going to happen. We won't end up in such a situation in the future when we have more water What you are trying to do now is actually contra productive in the sense that you teach people that if they do minor tweaks of things then they will get more water but it doesn't really influence anything on a larger scale.

CH: As it is now, we are already scaresed on water in the bigger cities in the world and surely many of them double or triple over time. Simply the water, we have to use less somehow

TH: yea because the technology progress in turning like saltwater into drinkable water is also like going very slowly, if I remember correctly.

CH: Yea but big cities are not located near the sea necessarily right?

TH: yea that's right

CH: i mean, a city like san francisco has water scarcity, its on the border of the pacific ocean and right near the mountains

CH: so i think that mass balance between, and can you virtually repr.

CH: i would argue that we shouldn't keep or increase the water consumption by creating a new water type, you should reduce water sources and get the ideas, show some of the ideas in the marketplace as that's really interesting

CH: and if you need inspiration for it, you could look at some of the projects being done in Germany. There are some city experiments where the government funded cities has been installed, typically around a 1000 people where they have, they have decided not to have water inlet. They only use water that has fallen from the sky, or re-use.

CH: there are projects like that around the world where you can get inspiration for many of these ideas.

LA: one of the topics we have sort of deliberated about internally is this fit-for-purpose idea of water, do you know?...

CH: yea but that is for instance, as you say the shower could be used for clean-flushing the toilet

LA: Is there anywhere where, or is there any work done what- how pure or how, what the quality of water should be to be fit for it.

LA: one of the things we are struggling is to get- the idea was to get an overview of what type of water, what quality of water can be used for X purpose

CH: i don't know how much work has been done, there has been done a lot of work, but i mean, from a quality point of view, what we don't want to be in the water.

There are two things we don't want to be in the water. One is, so to speak, outlet from humans, you don't want toilet waste in - of any kind - in your water, and then, there are three actually. The second one is, you don't want garbage from the kitchen containing earth and the vira living off of what you may need, growing on the meat, so to speak. So the kitchen waste you want to keep out to some extent. And then the last one is the chemicals used in household, and chemicals being very broad, especially cleaning agents, and then its what we do to ourselves to be beautiful or-and healthy, medicines and pharmaceuticals, and things you buy at Matas.

Those three things you want to keep out, and have been on, you can more or less re-use them being... toilet water can not be re-used in any way, before it has to some extent been disinfected or treated and the water that has been used, can be re-used without human contact. So you can use showers for gardening, you can do showers for toilets and so on.

TH: So that would for instance be if you've been boiling food... i guess?

CH: yea, that water could easily be used for flushing the toilet., because you disinfected it when you boiled it, right?

TH: yea, that is a relatively easy way of putting it up at least

LA: that could also be part of the mini-game universe here, what type of your own use of water

CH: and these changes in quality are really interesting to think on, how can they be re-used. Could you wash your car in something that i have showered in? - yes of course you could, if you want to wash your car at home - probably then. But still, it is not that critical, right? But when you consider these game events, do we use as little water as possible? And secondly, can we re-use the water after usage. And then just try it out, and then google it if it- what was actually in the- google the water type.

In respect to these - i mean if the kitchen, if it has been cooked to some extent, then it is home-free, that will kill whatever is in there, right? That's also why we can always eat cooked food without feeling sick. Toilet, we can also cook that, but it tends to be a bit messy, and then the rest, then thats ok, for re-use.

TH: so i guess then, one example of a goal that you would be able to set up in this would be basically to get your tap water back, like turn it back on

CH: yes, yes - for sure - yes. Those 50 liters that you can use now in south africa right? You have to have 2 liters of pure water for drinking for everybody, then you are down to 40, how do you want to use those - that is really really critical.

So you bring all your clothes to the dry cleanings. That really a reason to use a lot less water, it might be more expensive, but then you don't use for washing clothes at home. You don't have these de-centralized big water consumption - they are becoming better the washing machines - but nowhere near a dry cleanings installation, and that is actually clean enough. And - can you wash a 100 m3 a time, that uses a lot less water. A modern cleaning facility like "bernsen", the ones, you know, that provide towels they are cleaning - they use their water 7 times , they wash 7 times with the same water before they let it out into the - cleaning facility. So they use a lot less water.

LA: thats cool also for the experienced part of this. There are a lot of paradoxes you're facing here.

CH: but i think you should brainstorm the ideas in the game, and then you can have another round or another go.

CH: Or you can go into a house maybe, you could do what you actually thought would be right, and then see: this was your water consumption when you were there.

LA: and i still think this can be done without going for the behavioural change in - and more the awareness. Because again, the general purpose is making me aware that showering is almost your entire-

CH: it is also a funny exercise, going into - doing how you're used to, and then, please be aware of you not using water now, and going again - doing the right thing - and then put up the south African challenge - now you can only do this.

TH: you can actually start the entire game out with the introduction being - you don't have a water problem, yet so-

CH & TH: do as you normally do.

TH: and then you get to see, you used this much water- or you get a bill in the door the next day saying: oh, you used this much water, cut it down to "this" amount.

CH: yea exactly

Appendix B
AI Home Assistant Narration

1. Welcome home, everything is exactly as you left it this morning before you headed out.
2. As per your request, i would like to remind you that you wanted to install a new shower head in the bathroom, may i suggest you get it done right away?
3. In order to install the shower head, you first have to detach the old one by twisting it counter clockwise.
4. Good, now put the old shower head into the box.
5. Neat, now you just have to pick up the new shower head and screw it in clockwise.
6. All right, the new shower head should be able to last a long time.
7. In the most extreme cases, installing a new shower head can reduce water consumption by up to around 70
8. You also wanted me to remind you, that you had some issues with your pipes in the boiler room.
9. I suggest you go and take care of it right away before it escalates.
10. Oh dear, seems like your pipes have started leaking water, if you pick up the wrench, you should be able to tighten those bolts.
11. Great, now you can use the wrench to tighten the bolts which should fix your leakage.
12. Three bolts remaining!
13. Another two bolts remaining!
14. Just one bolt left!
15. Good job, you fixed the leakage.
16. In major cities, leaking pipes can be the cause of 80% of the water pumped out into the water system to be wasted, so good job on taking action.
17. You look rather famished, may i suggest you go prepare lunch in the kitchen.
18. Use the potato peeler to remove remove the skin from the potatoes. Don't forget to rinse the dirt and wipe grime off from the potatoes!
19. You can do many small things to reduce your overall water consumption, as long as you plan ahead a bit.
20. Oh right, you wanted to use the water from your meal yesterday to water the plants, go ahead and pour the water from the cooking pot into the plant pot.

21. You can reuse water that was used for cooking, bathing and more, just like you can use rainwater in various situations that don't involve consuming the water.

22. I know you have had a rough day, but i can't help but notice that the house is rather dirty.

23. I suggest you to go and get some cleaning utensils to resolve the matter.

24. Use the vacuum and mop in order to clean the floor. If the mop gets too dirty, go back and rinse it in the water bucket.

25. Neat, that was the last remaining dirt, and the cleaning utensils have been put back into their place.

26. When cleaning, it is not always necessary to use water. Sometimes a vacuum or paper towels might be sufficient enough.

27. Now you only have one task left for today, go into the bathroom and flush the toilet, as you seemed to have forgotten to do so this morning.

28. By replacing an old toilet with a new one, it can be possible to save up towards 80% more water when flushing. This is possible through the use of multiple flushing options and other optimisations.

29. Again, you can also reuse water to flush the toilet, as well as flushing the toilet less in general.

30. If it is yellow, let it mellow, as they say.

31. Since you are done with all your tasks, why not take a shower to relax and clean yourself?

32. Moisten your skin, then pick up the soap and rub it in, then, use water from the shower to rinse of any grime or dirt you may have picked up during the day.

33. Using a bathtub consumes a lot of water, with a general estimation of 120 liters of water used.

34. A shower uses less in general, but you can reduce the water consumption further by turning of the water while soaping yourself in.

35. Good, with all that out of the way, i suggest you to go to the living room and review your day at the projector.

Appendix C
Implementation/Design - Technical Aspect

C.1 Game Manager

The game manager keeps track on, what minigame id is currently active and if it is being played or not. The difference between being played and not played is whether or not the player has reached the area for the minigame.

It is also responsible for changing the active minigame when the previous game is over, when starting the first minigame and when the game is started.

C.2 Minigame Manager

The minigame manager handles what happens before a minigame starts, when a minigame can start and what happens after a minigame is completed.

The minigame manager makes it possible to configure whether a minigame uses water and if it is replayable.

C.2.1 Starting Minigames

All minigame managers have an ID, which is used by the Game manager to determine which minigame should be initialise. It listens to an event called "Changed-CurrentMinigame", if the id matches the Game managers id, it will be active and tell the player where to go. It will then wait for the player to arrive at the correct position, and start the actual minigame with the event "StartMinigame", which activates the scripts controlling the started minigame, this prevents the users from playing minigames that are not currently running.

C.2.2 Managing Water

Each minigame has a serialized bool, which controls whether the minigame should count water usage. If the game is counting water, it is expected taht there is a text field and progressbar associated with the task, which can be used to display the amount of water that has been used for the given task. There are two different events that the manager looks for in regards to water: a water toggle event called: ToggleWaterEvent, this toggles if the water is currently running or not. The amount of water spent per. second is controlled by a float.

The second event is a single time event called: SingleExecuteWaterUsageEvent, and adds a certain amount of water to the amount you have used, once for each time the event is triggered. The amount is determined by a float.

C.2.3 Ending Minigames

In the initial concept, it was discussed whether players should have the option to replay the minigames in order to try to get a better result. This feature was omitted in the evaluated build of the game however, as it was feared that it would complicate the results.

When a player has completed all tasks associated with a minigame, the minigame then checks if it is a task using water and if it is replayable. If the task is using water, it will update a list of floats that keep track on how much water was used in the different attempts of the tasks and sets the text of the projector in the living room to the best amount. If the game is replayable it asks if the player wants to retry the game, if the players picks yes, it will reset all variables related to the minigame and restart the minigame. If the player picks no, it will launch an event that tells the game manager to set the next minigame as the active minigame.

C.3 Events

The events system uses a subscribe system, where classes can subscribe to events and execute a function when a subscribed event is triggered. This allows for communication betweens systems that otherwise don't know about each other. This means events describe something that happened in the scene and allow other objects to act or react accordingly.

C.4 Placing and Holding Objects

There are multiple ways to interact with objects in VR space, here it will be described how the player picks up items from the environment with their hands.

The simplest way to make an object follow the hand is by making the object a child of the hand, and when the player drops the object, unchild the object. This will often require a bit of adjustment to the positioning of the object in order to make it look as if the character is holding the object in the hand. One method is to use offsets, the offsets can e.g. be the handle of the pot. Likewise, you can make an offset for the hand, where the game object's center position for the hand might be insufficient. One also needs to keep track on whether it is the left or right hand that colliding with the pot, this can done with a bool, whereas both offsets can be obtained through the use of empty game objects.

It is then possible to calculate the position you want to place the object before making it a child. The calculation for the offset is: position = position + (hand_offset - object_offset).

C.5 Narration

The narration is made using the microsoft text to speech synthesiser called SAPI. In order to make SAPI work in unityn one needs to download a DLL and place it in ones unity project folder.

C.5.1 Settings

SAPi has a few options to alter the voice outcome of the speech synthesis. First, one makes a new speech object: SpVoice voice = new SpVoice(). The speed can then be adjusted with: SpVoice.Rate and the volume with: Sp.Volume by using integers between 0-100. The speech synthesis uses the voices stored in the windows systems, and can be changed with: SpVoice.Voice = SpVoice.GetVoices().Items(ID), where id is an integer.

C.5.2 Voice Events

To make the API start speaking, one uses SpVoice.Speak (string, SpeechVoiceSpeakFlags), the speech is running in a streamline, so triggering multiple speech events will queue up the sentences into a sequence, rather than cut off any already running speech. It is also possible to get the status of the speech API and check whether or not in is currently speaking. This is useful for executing code after a speech event. A way to accomplish this is by starting a coroutine and wait while SpVoice.Status.RunningState != SpeechRunState.SRSE.Done. The reason for checking for “not done” instead of running, is that the API sometimes returns integers as status. If there is any black space in the streamline between words, it means that it is in the middle of a sentence, but just not speaking words.

To ease the use of using the speech synthesiser and only require to make one instance of the SpVoice, it is using the Event systems, and listening to the narration event TextToSpeech Event that takes a string. It is that string which is read aloud.

C.6 Player Feedback and Feedforward

C.6.1 Highlighting Interactable Objects

One feedforward method used in the game is to highlight objects that are interactable if they are in proximity of the player. This is done by using a silhouette enhancement shader, which set the silhouette intensity to 0 while the player is not in proximity and starts ping-ponging between two values when the player gets close enough.

Although this feature was desired and is working on a code level, it was not implemented into the evaluated build due to time constraints and priorities.

C.6.2 Vibrations and Haptic Feedback

The HTC vive controllers have the option to provide haptic feedback, this is done by sending a haptic pulse with a defined strength.

In order to achieve a more natural haptic feedback, two different haptic feedback behaviors were made, each with the same basic structure. The basic structure allows for the definition of the strength of a pulse, the time between pulses and how long it should keep vibrating.

The first extension to the basic structure incorporates a randomisation element, where the strength of each pulse is randomised between a maximum and minimum value. The second extension allows the time between each pulse to be altered by an animation curve.

C.6.3 3D Progress Bar

The 3D progress bar is used to visualise how close the player is getting towards the recommended limit for a given task. The bar is a 3D cylinder, which is scaled from 0 to 1 on the y-axis, and changes color from green to a red. Though no numbers are show, it still fulfills the purpose of providing the player feedback on how close they are getting.

C.7 Waypoint Manager

A navmesh is used to check, where the player can teleport. The navmesh is baked from the waypoints meshes that are placed around the scene, which means that the player can only teleport to these areas. In order to further guide the player, the waypoints that don’t lead to an active minigame are blocked and made transparent.

Appendix D
Visuals -Technical Aspect

This chapter goes through the various techniques and tools used for creating the visuals. All the models and textures that ended up in the game were custom made, meaning no models or textures created by third parties were used. In order to save time and improve the end result, some third party shader solutions were used.

D.1 Mesh Creation

The various household object were created through the use of reference material gathered online. A big focus was on making sure the meshes were relatively low poly in order to improve performance. A lot of work went into making sure that the smooth shading would look decent by chamfering the edges that had to be smooth. This ensures that light hitting the objects look more believable, as well as the shading itself. Figure D.1 shows an example of a model that was created and used.

Figure D.1: The finished mesh of a potted plant, which was used for the game.

Instead of relying on the angle between edges in order to determine sharp edges, the edges that had to be sharp were marked as such manually, thus giving full control of the shading of an object, which in turn can reduce the poly count. An example of the marked sharp edges can be seen in Figure D.2.

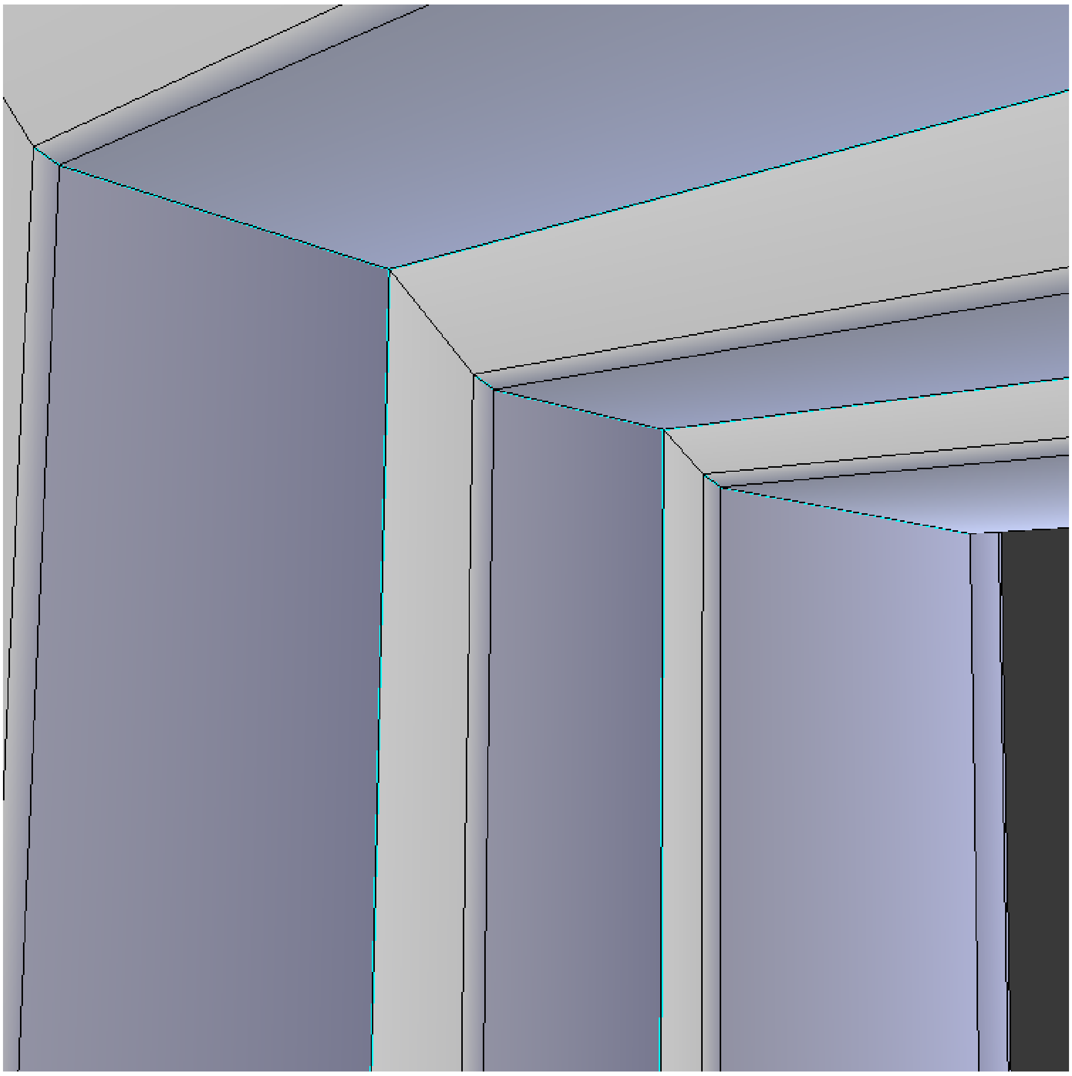

Figure D.2: An example of defining sharp edges, highlighted in cyan within Blender.

In some cases, the meshes had repeating geometry, which were made sure to have the same proportions and so forth in order to make them more UV space efficient later on. Instead of exporting the models into the .fbx format by hand, a modified import script was used to keep it consistent within the Unity work-space, and removes an element of human error. This approach also gets rid of the usual 90 degree rotation that is applied when exporting manually.

To begin with, the meshes were not UV unwrapped or textures, so first, all required meshes were done in order to get the shapes right, before moving on and potentially wasting time on assets that would never be used. This also made it possible to integrate the meshes into the functionality of the game right away.

D.1.1 Master File and Linked Mesh Data Workflow

In order to be consistent with the style and proportions, a "parent - child" structure was used when implementing the various models. This means that there is a master file that contains all mesh data for the various household objects, which are then linked to from external files for each objects or set of objects. As an example, the potted plant consists of a pot and the plant itself. The mesh data for these are present in the master file, and properly named. Then there is a file called "potted_plant_01" which links to the pot and plant present in the master file. An overview of what the structure looks like in Unity can be seen in Figure D.3, where the master file is highlighted with red.

Figure D.3: The folder structure of the parent - child setup, seen from within Unity.

This approach ensures that all mesh modifications can be done within the master file, that shared materials are easier to manage to avoid duplicates, as well as leaving out redundant meshes that were used for either testing or scaling, without the need to remove them.

There are some drawbacks, however, as it turns out that Git does not track the re-importing of child files as version changes. This means that each change made in the master file will not be applied to the child files, unless the child files are re-imported on each system that the game is being worked on. A semi-solution is to wait with re-importing the final version of the meshes until they are completely ready, or find another solution with the version control system itself.

Because the child objects rely on mesh data from an external file, these files are about the same file size as they mostly contain references. This also means that any set-up for materials and so forth only has to be stored once in the master file, as those are also referenced. Further small optimisation's could be to reduce the amount of default clutter in the child files, such as lights and cameras.

D.1.2 Scale and Proportions

Due to the nature of VR, and the relative realism of the setting, it was important to keep the scale and proportions of the various objects close to reality. This was done by finding measurements online, taking them from personally owned household objects, or simply eye-balling it based on its relative shape and size to other correctly proportioned objects. As can be seen in Figure D.4, reference character planes and the modelled hands were used to evaluate proportions before being tested within the VR space.

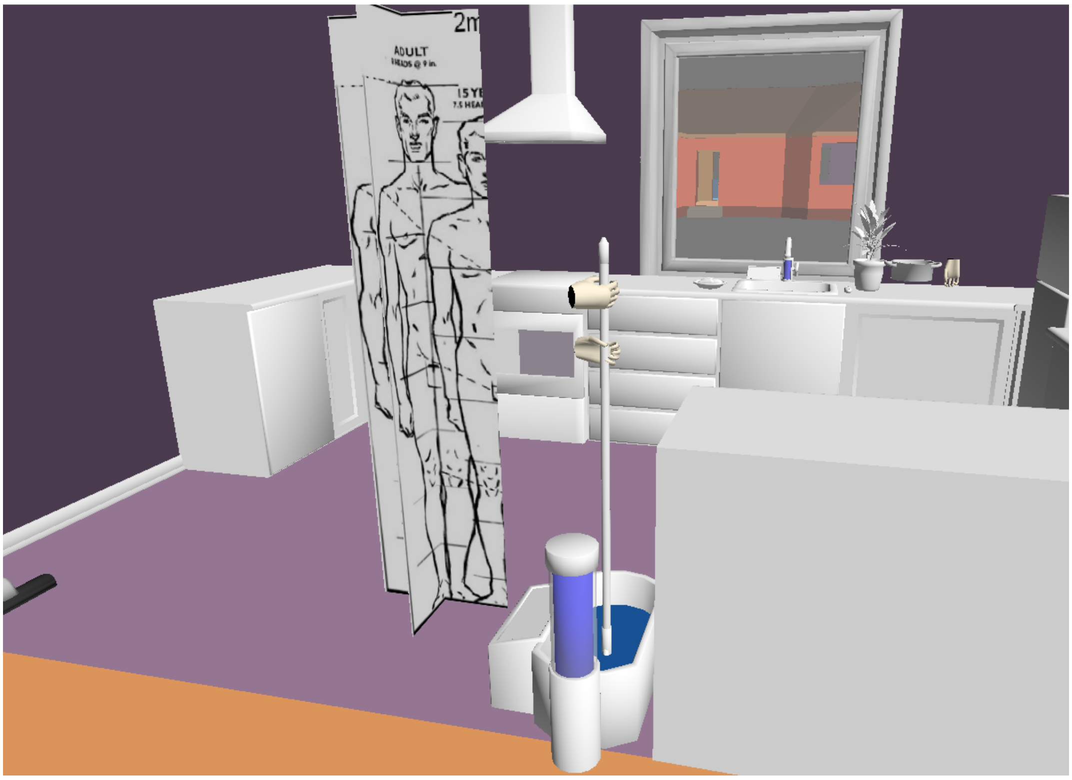

Figure D.4: An example on how planes with a scaled human and the modelled hands were used to evaluate scale and proportions.

Apart from the surroundings, the player's body also had to be somewhat believable. Again, a reference was used as a texture to model the shape of a torso and a set of hands. As one of the big difficulties within VR is to make proper locomotion of the body with little tracking, it was decided to make a "Rayman" type character where you only have the hands and the torso. These can be seen in Figure D.5.

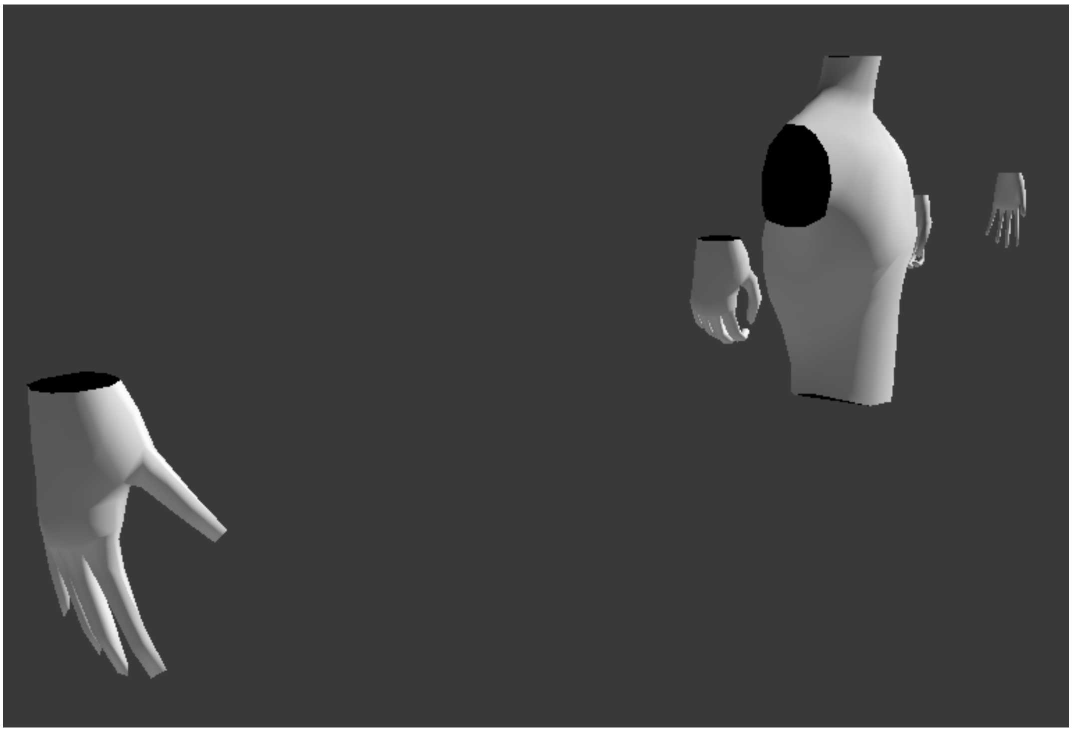

Figure D.5: The master scene containing the character meshes

As a side note, nothing was animated within Blender, nor was anything rigged. This was done to save implementation time, though a temporary solution was made where the hands have two separate meshes that were modified per vertex instead to form a clasping form.

D.1.3 UV Unwrapping

Once all the meshes were done, they were subsequently UV unwrapped. Where applicable, UV faces would be layered on top of each other in order to re-use UV space. An example can be seen in Figure D.6 where there were three variation of the leaves which were re-used and randomly placed to form the plant.

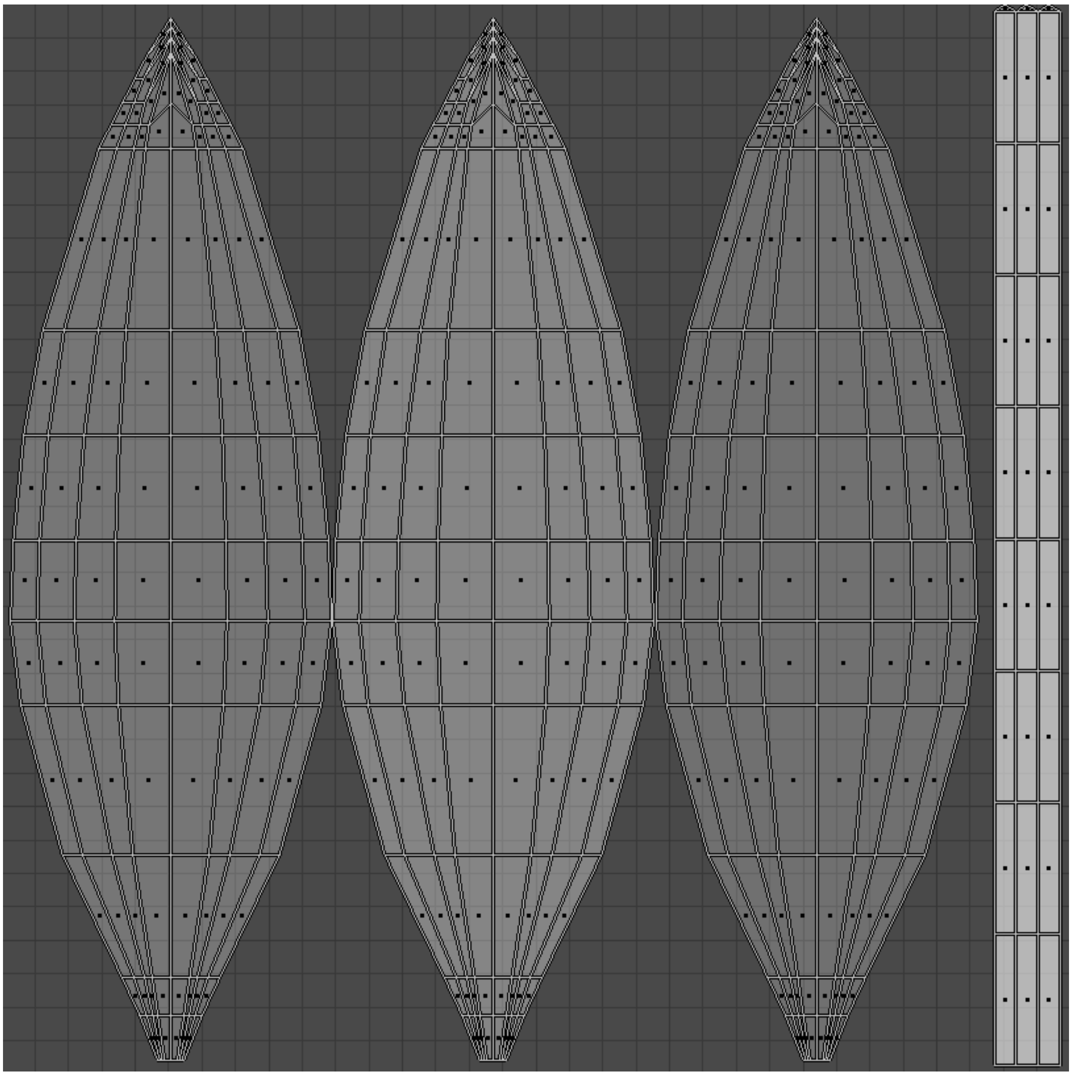

Figure D.6: The unwrapped UV for the plant.

In many cases, it was possible to project the UVs instead having to stitch them together, this was especially useful on all chamfered cylindrical objects, as unwrapping the end caps would normally warp and stretch the UVs instead of creating perfect symetrical UV islands.

D.2 Texture Creation

The texturing process was kept relatively simple. No mapping for normal, bump, metallic, specular, and so forth, were created. Only a few objects had mappings such as for emission. This was done to both save on processing power, but also to make asset creation faster. Due to the hand painted style used, it is possible to paint in the suggestion of reflective surfaces onto the textures directly. An example of a finished model with painted textures can be seen in Figure D.7.

Figure D.7: The finished potted plant.

The UVs were imported into photoshop, and used as a frame for the various objects. Then, the main colors were painted, along with layers for highlights and shade, then finally a bit of noise and overlay effects to finalize the texture. An example of the texture made for the plant can be seen in Figure D.8.

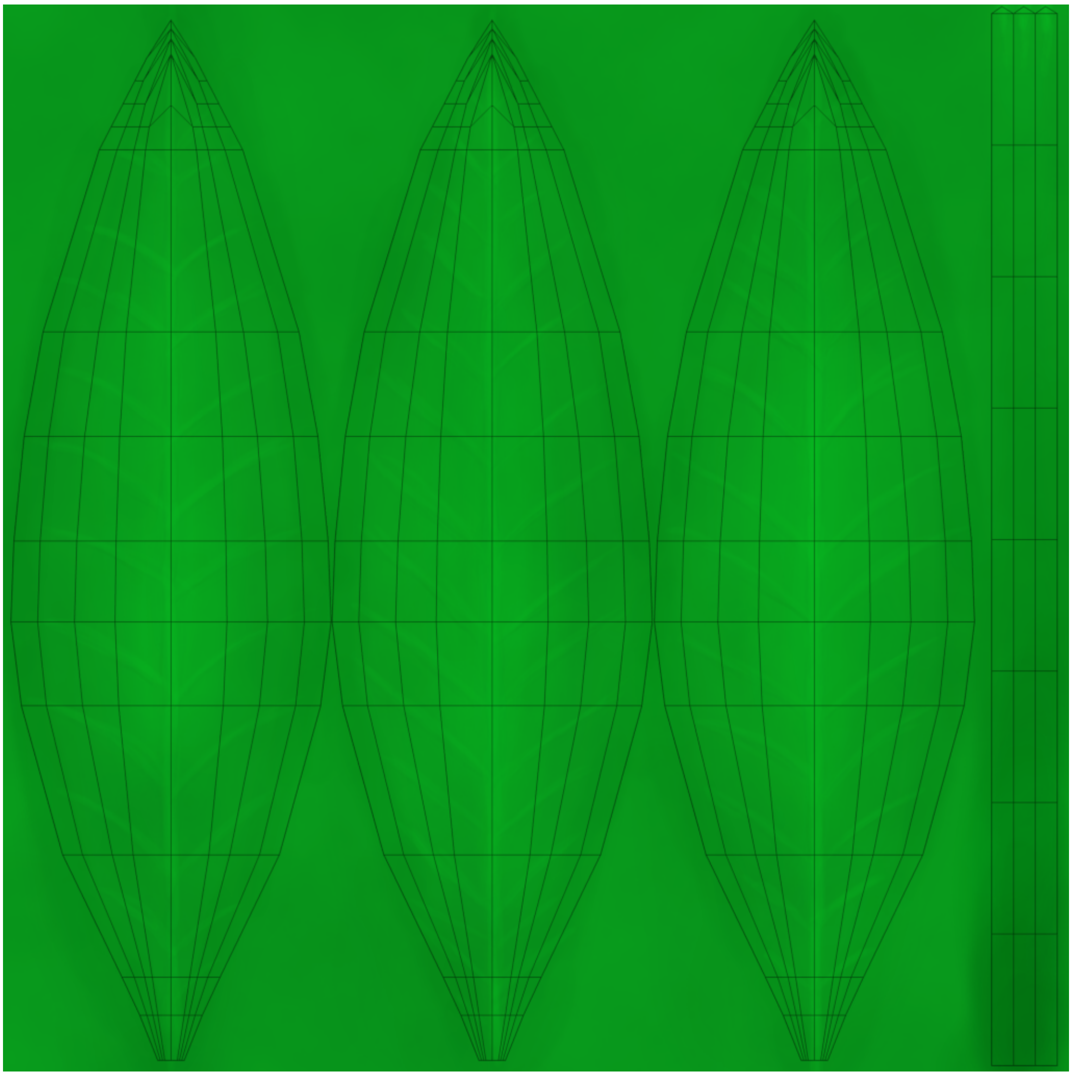

Figure D.8: The finished texture for the plant, with an overlay of the unwrapped UV.

D.3 Lighting

Lighting consists of a directional light source that simulates the sun, as well as interior lamps and point lights emphasising the light coming in from the windows. In order to create a bit of random contrast for the exterior, a noise cookie was used on the directional light, in order to simulate the effect of clouds. The ceiling lights inside the house are the primary light sources that light up the various rooms.

Their values were tweaked to meet the needs of each room, so although they appear as the same type of light, they actually have varying settings. As a final touch, a point light was placed at each window in order to simulate an emphasised spill light from the outside. This creates a subtle effect that lights up the rooms in a more naturally-ish feeling way.

D.4 Shaders

Various shaders were used in order to improve the quality of the visuals. As mentioned in the beginning of this chapter, some of the more complex shaders were 3rd party shaders.

D.4.1 Shader Forge

In order to create the custom shaders needed, Shader Forge was used. It allowed for quick prototyping and implementation of working shaders. An example of a node network created for one of the custom shaders can be seen in Figure D.9.

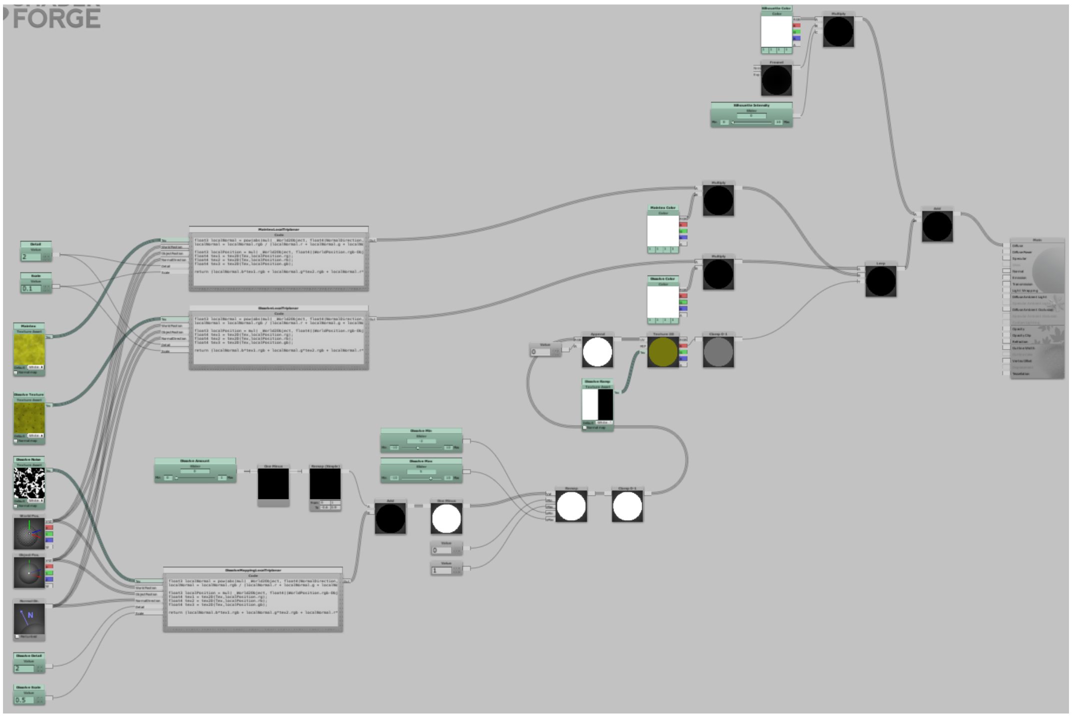

Figure D.9: The node network for the shader that handles the dissolve effect for the potatoes.

By making shaders, we could use a dissolve effect in order to gradually peel the potatoes and make the character clean within the game. An alternative would likely have been the use of multiple pre-processed textures for each stage, which makes it harder to make the effect change gradually.

D.4.2 UV Free Shader

One of the two third party shaders used is called "UV-Free", which is a tri-planar projection shader package that contains shaders that can be used on both game objects and terrain plates, as well as other variants for more complex needs. Figure D.10 visualizes one of the toughest hurdles to overcome when limited to one 2D mapping for textures, and thats is irregular shapes such as spheres.

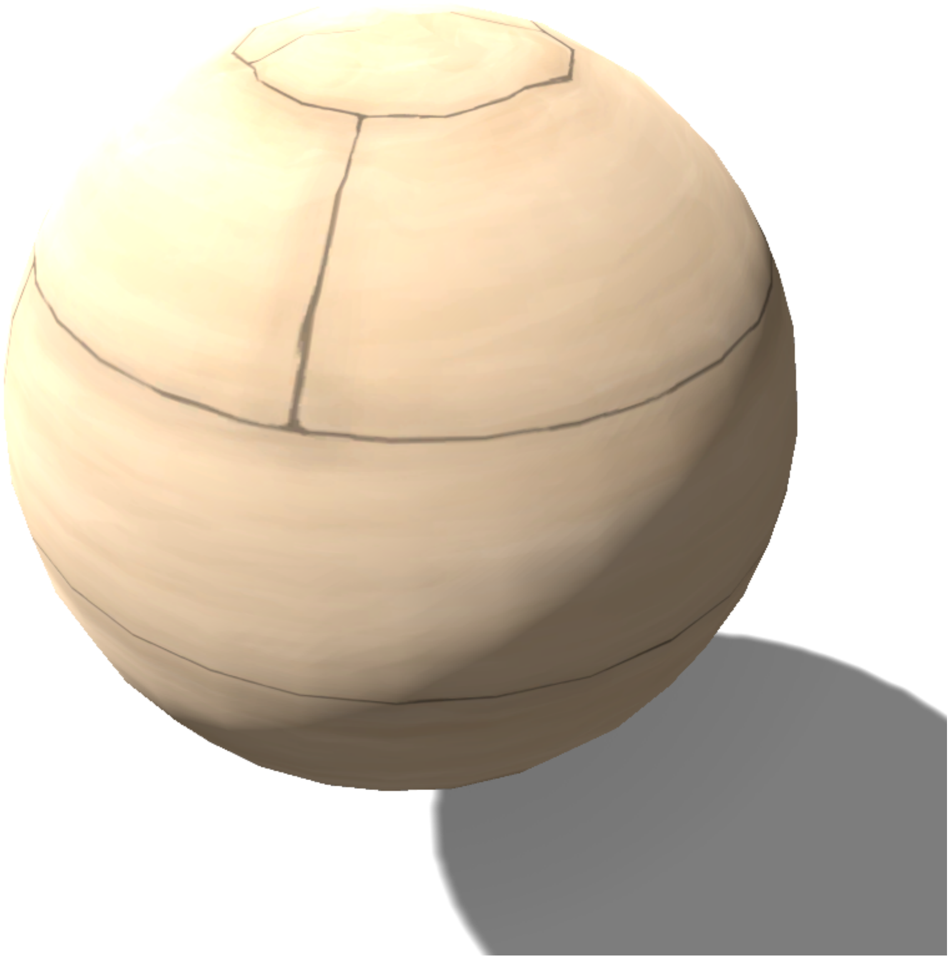

Figure D.10: An example of using the Unity standard shader on a Unity sphere.

As can be seen, the texture becomes warped the closer it gets to the poles of the sphere. Through regular UV unwrapping, it is also hard to avoid obvious seams without causing any stretching. Tri-planar projection is the method of projecting a texture along three planes, namely along the x, y and z directions, either in world or local/object space. An application of the method can be seen in Figure D.11, through the use of UVfree.

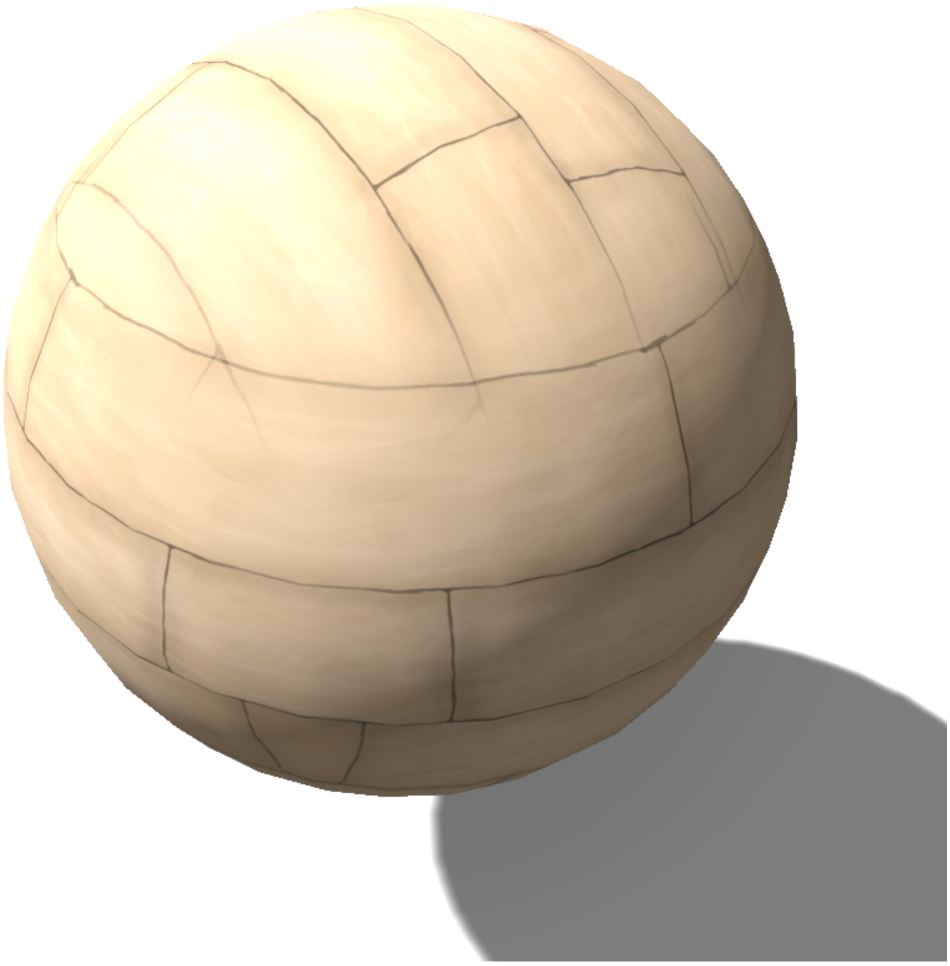

Figure D.11: An example of using the UVfree shader on a Unity sphere.

Although it is relatively easy to implement a tri-planar shader within shader forge, it is rather difficult to get it working for terrain plates, which are a really good application field for these types of shaders. Instead of stretching the textures when you create a rise in the terrain, the texture gets projects on another axis instead. There are various methods for doing the mapping itself, which can be more suitable for specific use cases.

For the game, UVfree was used for both the exterior terrain, but also for the walls, floor and ceiling of the house. This also makes it possible to keep the scale of the textured planes consistent across all the meshes.

D.4.3 Advanced Foliage Shader

In order to create a more interesting vista outside the windows, the Advanced Foliage V5 shader solution was used. It uses vertex paint on a mesh similar to weight painting when rigging a character or similar. The different colors are mapped to various shader functionality that cause a vertex offset on the applied mesh. This causes the trees and grass to wave and bend, simulating the effects of wind. The shader solution also supports normal, translucency and smoothness mapping, which can be seen in Figure D.12.

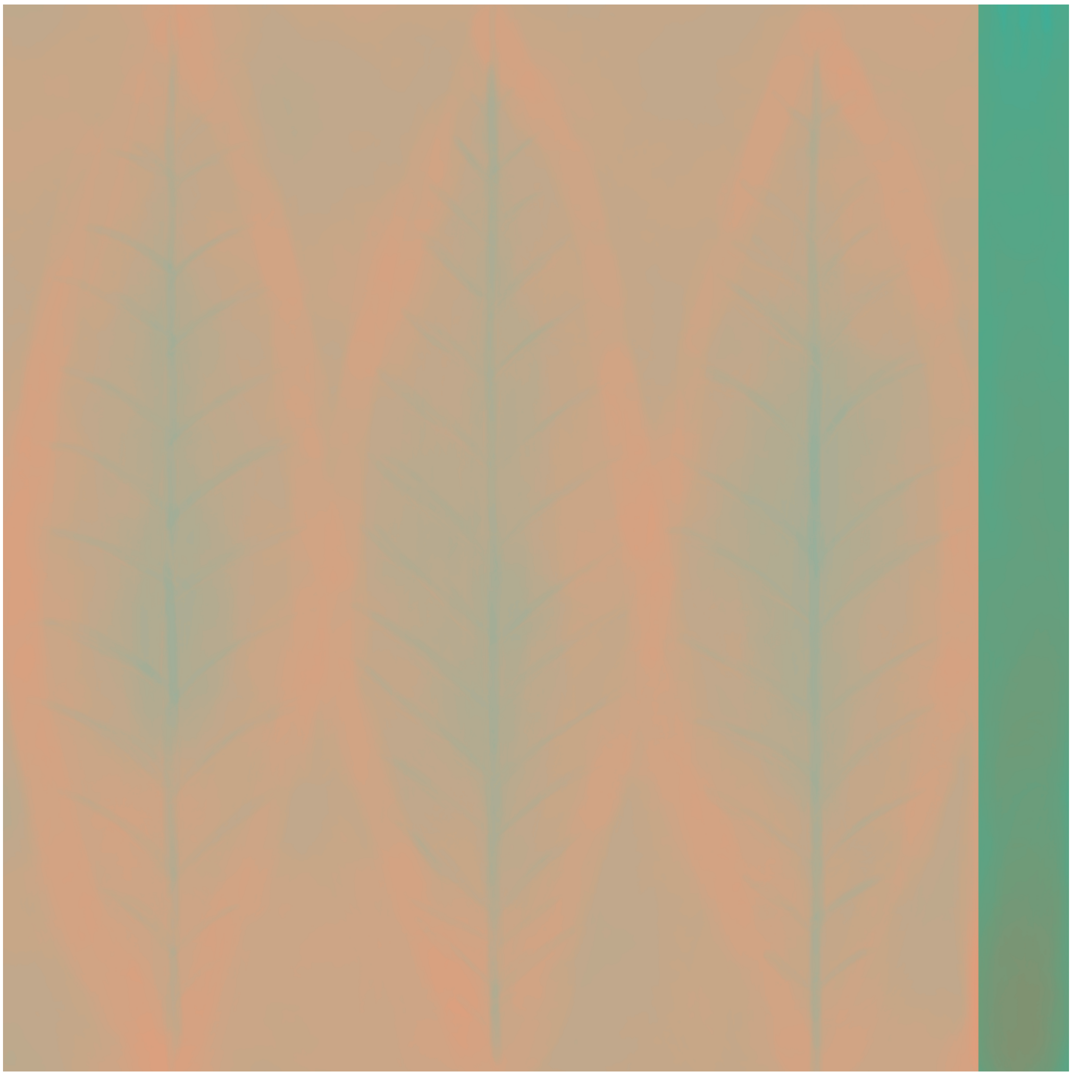

Figure D.12: An example of the NTS mapping for the potted plant.

The mapping uses a custom RGBA texture where each channel contains the information for the previously mentioned 3 features. Tools can be used to create the various mappings, where normal mapping uses 2 channels, with translucency and smoothness using 1 channel each.

D.5 Post Processing

To make the scenery and light pop, post processing was used to achieve bloom and ambient occlusion. Figure D.13 is an example of not using any post processing.

Figure D.13: A visualisation of the game with post processing disabled.

Everything in the scene looks very flat, and the light coming in from the window is rather dull. Through the use of Unity's post processin stack, it is possible to apply a myriad of post processing effects to the game camera. Figure D.14 shows the same scene with bloom and ambient occlusion applied.

Figure D.14: A visualisation of the game with post processing enabled.

The ambient occlusion aids in providing better contrast where edges meet, while bloom makes bright light pop more, which in this case provides a better feeling of a bright outdoor sun and warm weather. Post processing effects can be quite taxing on processing power, but it can provide a much better result.

D.6 Real Time Renders

This section contains a series of real-time renders from the house interior and exterior in order to provide a better idea on the end result.

Figure D.15: Real-time render of the living room.

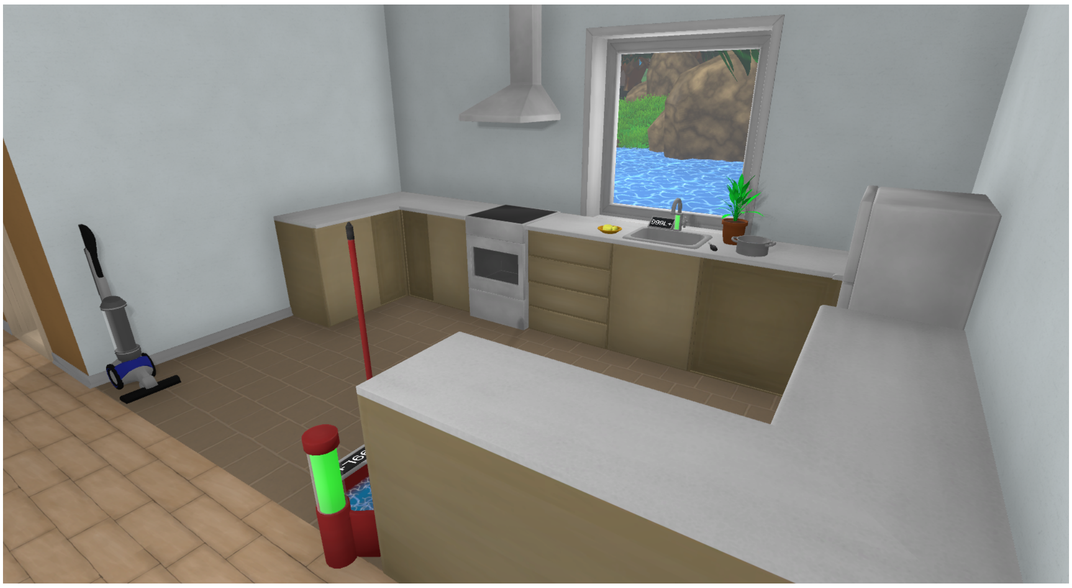

Figure D.16: Real-time render of the kitchen.

Figure D.17: Real-time render of the bathroom.

Figure D.18: Real-time render of the boiler room.

Figure D.19: Real-time render of the exterior which can be seen from inside.

Appendix E
Evaluation Procedure

Materials list
This procedure, printed
VR gear (pc, stands, HTC vive)
Wipes for disinfection
Cookies for participants?
Traditional material, printed

Part 0:
Set up everything (stands, pc, HTC Vive)
Make sure that the pc is running optimally
Do a test run of the game to make sure it is all working
Do a sound check

Part I:
Determine whether they will play game first, or experience traditional material
Prepare material
Set the correct minigame ID in the game manager

Fetching participants
*Ask if they want to participate in a medialogy master thesis evaluation, which is about spreading awareness about limiting water consumption through the use of VR"

Estimate 35 minutes for testing

Introduction
Casually introduce the participant to the project group

Inform them about the purpose of the evaluation (no harm in repeating intent):
"To investigate how VR can be used to spread awareness, in this case about water consumption, compared to more traditional methods such as a presentation or internet pages."

"The evaluation consist of several questionnaires that we would ask you to fill out to the best of your abilities, as well as experiencing the VR game we made, and some more traditional material"

"We would like to note that the data we collect here will only be used for research purposes, and that there are no personally identifiable questions"

Part II:
Initial questionnaire
"To begin with, we would ask you to fill out an initial questionnaire, in order for us to establish a baseline"

let participant fill out questionnaire

First experience
"We would now like you to experience. . . "

if VR Remember to teach controls and tell them to say so if they feel uncomfortable so we can adjust the HMD or stop the test if they feel sickly

Expose participant to the first experience (game or traditional)

Second set of questionnaire
"Now that you have experienced the first material, we would ask you to fill out this second questionnaire"

let participant fill out questionnaire

Part III:
Second experience
Depending on which experience they did first, expose them to the other now

"We would now like you to experience…"

if VR Remember to teach controls and tell them to say so if they feel uncomfortable so we can adjust the HMD or stop the test if they feel sickly

Third set of questionnaire
"Now that you have experienced both the VR game and some traditional material, we would like you to fill out this last questionnaire"

let participant fill out questionnaire

Debrief
Thank participant for participating, present them with the option of getting a cookie for participating

VR controls
Use the trackpad on the top as a button, in order to get a teleport marker. You can teleport to the green areas.

Use the trigger underneath, in order to pick up, drop, or use items.

When putting items down, don't press anything, just hold the item close to the place where u took it.

We recommend you to teleport around more than walking, as you might otherwise need to take a few steps back in order to teleport close enough to where you need to be

Appendix F
First Half of Traditional Material

On saving water
There are many factors that influence water consumption, both within your own household, as well as out in the world.

The water usage of a shower is influenced a lot by which shower head the shower uses, where some water saving shower heads can reduce the amount of water used and still receive a similar effect by infusing the water with air.

In the most extreme cases, installing a new shower head, for example, could reduce your water consumption by up to around 70%. To put that percentage into numbers, a water-reducing shower head use around 6 to 10 liters per minute, whereas an older shower head can use up to around 16 to 18 liters per minute.

On a much larger scale, leaking pipes are a big factor in wasting water. Within major cities, up to around 80% of the water being pumped through the pipe systems, is wasted due to old pipes that are leaking.

Appendix G
Poster for the First Half

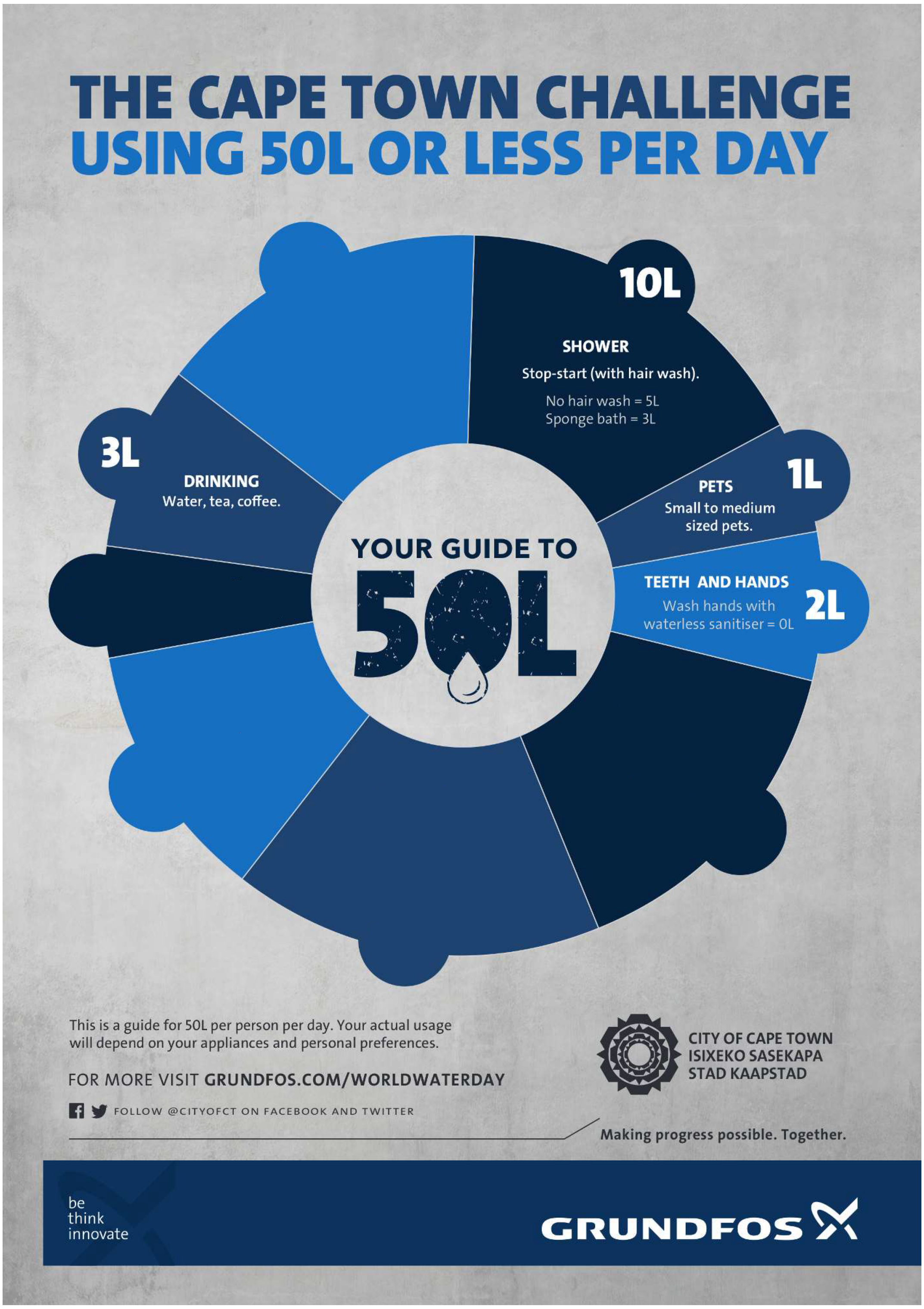

Figure G.1: This is a modified version of the poster made by Grundfos, for the cape town challenge.

Appendix H
Second Half of Traditional Material

On saving water

There are many factors that influence water consumption, both within your own household, as well as out in the world.

Doing daily tasks you use a lot of water, it is possible to re-use the water from various tasks for different things. You can e.g reuse the water from cooking and bathing in different situations like watering plants, flushing the toilet and more. In general, water that has been in contact with humans outlets, chemicals or dirt should not be re-used in areas such as drinking, but in many cases, boiling the water can sterilize it making the otherwise polluted water reusable.

In different cases it is also possible to reduce the water usage, when cleaning by only using water, when it is needed. There's times, where a broom, vacuum, or towel might be sufficient to get the job done.

A big part of the water usage in the home goes to flushing the toilet, especially for old toilets. Older toilets where the cistern and toilet bowl are built together use approx. 9 liters per flush - some even more. Modern toilets today with multiple flush options use approx. 6 liters for a big flush and 3 liters for a small flush. There are also modern toilets with multiple flushing options that use 2 liters for small flushes and 4 liters for big flushes. In some cases you can save 80% water by replacing an old toilet with a modern toilet that has multiple flushing options.

Appendix I
Poster for the Second Half

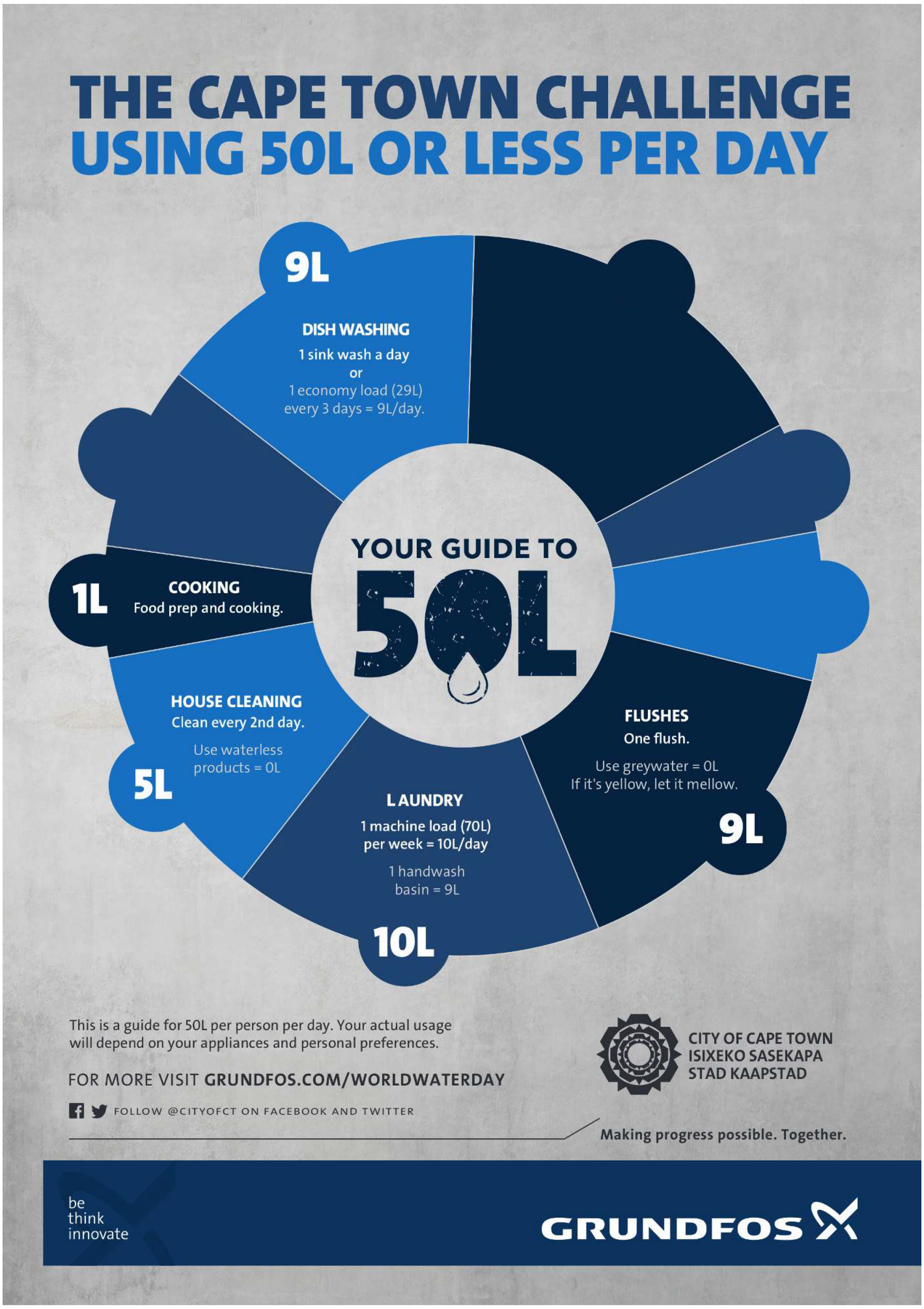

Figure I.1: This is a modified version of the poster made by Grundfos, for the cape town challenge.

Appendix J
Intrinsic Motiviation Inventory Questionnaire

The following are the various questions that were used for the IMI questionnaire.

Interest/Enjoyment

- I enjoyed doing this activity very much.
- This activity was fun to do.
- I thought this was a boring activity. (R)
- This activity did not hold my attention at all. (R)
- I would describe this activity as very interesting.
- I thought this activity was quite enjoyable.
- While I was doing this activity, I was thinking about how much I enjoyed it.

Pressure/Tension

- I did not feel nervous at all while doing this. (R)
- I felt very tense while doing this activity.
- I was very relaxed in doing these. (R)
- I was anxious while working on this task.
- I felt pressured while doing these.

Value/Usefulness

- I believe this activity could be of some value to me.
- I think that doing this activity is useful for, raising awareness about water consumption
- I think this is important to do because, it can raise awareness about water consumption
- I would be willing to do this again because it has some value to me.
- I think doing this activity could help me, to understand water consumption better.
- I believe doing this activity could be beneficial to me.
- I think this is an important activity

Appendix K
Usability Questionnaire

The following are the various questions that were used for the usability questionnaire.

- I think that I would like to use this system frequently.
- I found the system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the various functions in this system were well integrated.
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use.
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.

Appendix L
VR Sickness Questionnaire

The following are the various questions that were used for the sickness questionnaire.

General discomfort none slight moderate severe

Fatigue (weariness or exhaustion of the body) none slight moderate severe

Headache none slight moderate severe

Eye strain (weariness or soreness of the eyes) none slight moderate severe

Difficulty focusing none slight moderate severe

Increased salivation none slight moderate severe

Sweating none slight moderate severe

Nausea (stomach distress) none slight moderate severe

Difficulty concentrating none slight moderate severe

Fullness of head (sinus pressure) none slight moderate severe

Blurred vision none slight moderate severe

Dizzy (with eyes open) none slight moderate severe

Dizzy (with eyes closed) none slight moderate severe

Vertigo (surroundings seem to swirl) none slight moderate severe

Stomach awareness (just a short feeling of nausea) none slight moderate severe

Burping none slight moderate severe