Master's thesis

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Raising awareness about climate change and heritage preservation in Trondheim City with fire in VR

Developing an educational VR experience using the omnidirectional treadmill, Virtuix Omni

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"Virtual reality is the 'ultimate empathy machine.' These experiences are more than documentaries. They're opportunities to walk a mile in someone else's shoes."

Chris Milk

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Abstract

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Virtual Reality provides unparalleled immersion compared to traditional forms of gaming and introduces great opportunities for use in educational purposes. The immersion of VR provides an easier way to experience the effects of urgent issues like climate change that is otherwise difficult for many people to fully comprehend. Previous research shows that people can learn about complex social and environmental issues, and the interconnections between them, when information is brought to them in an immersive format.[1]

The goal of this project is to raise awareness of the interconnected issues/aspects of climate change and heritage preservation in Trondheim City using a fire scenario in VR and an omnidirectional treadmill, to provide an active learning experience. For the new application, two VR prototypes are developed and tested through empirical studies; [1] the first is concerning climate change, while the latter is focusing on cultural heritage preservation. Background studies analyze "Climate Quest" [2] to determine what improvement can be made, and how fire can be used in the application. These studies, combined with an evaluation based on well-established research regarding game theory, form the requirements of a new application called "Fire Quest".

In total, over 100 people participated in the background studies and the various studies for "Fire Quest", including a VR expert who tested both prototypes. The results show that most people did not learn much new information regarding climate change after trying the application because they were already well informed on the topic; however, it did serve as a good reminder of the dangers of climate change. The participants also acquired new knowledge from the experience about both the cultural heritage preservation in Norway, and especially about the fire safety of Nidarosdomen. After the experience, most people agreed more is needed to do be done to protect Norway's churches. In addition to this, the results show that most people believes the omnidirectional treadmill provides a more immersive and realistic experience and that they would remember the experience better because of it. Lastly, almost all participants enjoyed the gameplay and considered it a fun experience.

[1] https://www.youtube.com/watch?v=OyICVqlTzZI

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Abbreviations

XR	E**x**tended **R**eality
VR	**V**irtual **R**eality
AR	**A**ugmented **R**eality
MR	**M**ixed **R**eality
HMD	**H**ead **M**ounted **D**isplay
IMTEL	**I**nnovative I**m**mersive **T**echnologies for **L**earning
FOV	**F**ield **O**f **V**iew
HTC	**H**igh **T**ech **C**omputer Corporation
OLED	**O**rganic **L**ight **E**mitting **D**iode
DK	**D**evelopment **K**it
HP	**H**ealth **P**oints
UX	**U**ser E**x**perience
UEQ	**U**ser **E**xperience **Q**uestionnaire
SINTEF	**S**tiftelsen for **IN**dustriell og **TE**knisk **F**orskning
TBRT	**T**rondheim **B**rannn og **R**edningsv**t**jeneste
DTM	**D**igital **T**errain **M**odel

Chapter 1

Introduction

1.1 Motivation

”Arbeidsgiverorganisasjon for kirkelige virksomheter” (KA) published a report in 2017 on the current state of the Norwegian churches, in terms of safety, security, climate challenges and more. Out of the 1633 churches, there are in Norway, 566 of them are built with stone, steel, or concrete, while 1067 of them are churches made of wood. Almost 60 percent of the churches are under antiquarian protection through the Cultural Heritage Act (Kulturminneloven) or through other government regulations. (KA, 2018) [3]

1.1.1 Climate change

The report details the consequences of climate change on Norway's churches and determines the future repercussions from it. Higher temperatures, frequent and more rain, more avalanches, and a rise in sea level are all factors that contribute to the deterioration of the churches in Norway. The Norwegian Meteorological Institute published a report that analyses the dangers of rotting buildings close to the sea. (see: 1.1). Using this report, it is possible to determine how many churches are within the zone that has a high chance of rot (see: 1.2). Historically, most churches are within the yellow zone; however, due to climate change, over half the churches will be in the danger zone in the near future.

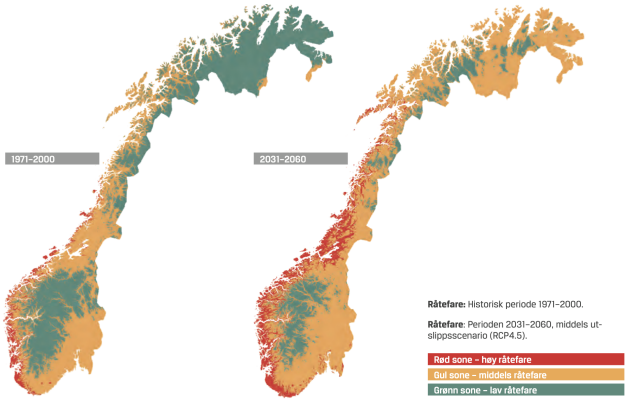


FIGURE 1.1: Large areas around the coast of Norway will be in a zone with high possibility of rot. A lot more will be in the yellow zone, with only some remote areas in the green zone.

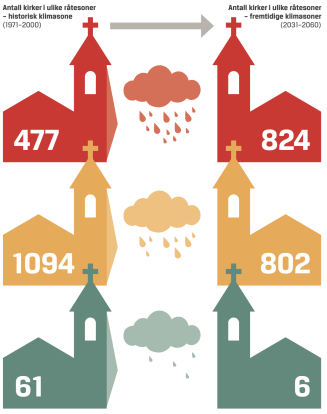


FIGURE 1.2: The amount of churches that will be in each zone due to climate change.

1.1.2 Cultural heritage preservation and fire safety

The report also considers the fire safety measures currently implemented in the churches. Only 12% of the churches have automatic fire extinguisher systems, and 68% have a direct notification to the fire department. The KA recommends these percentages to be 60-70% and 100%, respectively, which is far from reality. Of the fire alarms that are installed, there are 26% that were installed before 1998 and are due to be renewed. These numbers indicate that there is a lot of room for improvement in terms of the maintenance and cultural heritage preservation of Norway's churches and form the motivation for this thesis.

The aim of this thesis is therefore to raise awareness of the interconnected issues of climate change and heritage preservation. This interconnection is probably most visible and dramatic in a fire scenario of one of Norway's churches, which is the main reason for using Nidarosdomen as the virtual environment for the application. To make the experience more active, realistic, immersive, and to provoke a stronger emotional response, the omnidirectional treadmill, Virtuix Omni is utilized. The final result is an educational VR application that provides informational videos about the topics, and allows the player to experience the reality of a fire starting in, or around, Nidarosdomen cathedral.

1.2 Facilitating learning about climate change

We have known for decades that human-made CO2 emissions affect the global environment, with dire consequences such as rising temperatures, melting ice caps, sea level increases, extreme drought, forest fires, and more frequent and severe weather catastrophes. In fact, already in 1967, Syukuro Manabe and Richard. T. Wetherald explored what effect doubling of CO2 content in the atmosphere would have on the global temperature and predicted that it would cause the surface temperature to increase by 2.3C or 1.3C (depending on the distribution of relative/absolute humidity). (Manabe at al, 1967)[4]

A direct consequence of the increased global temperature is more frequent and severe forest fires around the world. A study from Canada used two GCMs as well as historical relationships between weather/fire danger and area burned and suggested an increase of 74-118% in area burned by the end of this century. (Flannigan et al. 2005) [5] If the CO2 levels double, another study suggests that the fire season length in Canada will increase by 22%, or an equivalent of 30 days. (Wotton and Flannigan, 1993)[6] These predictions seem to hold merit as another similar study suggested that the actual observed increase in area burned in Canada during the last four decades is directly linked to the result of human-induced climate change. (Gillett et al. 2004)[9] Similar results are expected around the world too. Not only do forest fires cause dramatic economic and social difficulties in the affected areas, but it also contributes to more CO2 released in the atmosphere, leaving a vicious negative cycle. In fact, a study from 2001 indicated that forest fires in Canada released approximately 27 Tg carbon per year and, in some years, actually surpassed 100 Tg, which is the same amount of carbon released from burning fossil fuels in Canada. (Amiro et al. 2001) [10]

1.2.1 Climate change and VR

Climate change is affecting everyone, with some changes more apparent than others. A recent study showed that average barley yield losses worldwide ranged from 3% to 17% due to drought and heat extremes. This, in turn, leads to increased global beer prices - such as a startling 193% price increase in Ireland. (Wei Xie et al, 2018 [7]) Naturally, a threat to the availability and economic accessibility of beer is both newsworthy and

alarming for most people. However, not all consequences of climate change are equally apparent. Climate change is a complex issue which, for most people, is difficult to fully grasp because one does not see the environment changing first-hand or on a regular basis. (Schuldt et al., 2016 [8]). When you do not see the immediate changes personally in your life, it might be challenging to take action and make changes in your own life. Adding to this complication is the fact that people cannot visibly see the results of their contribution to preventing climate change instantly. Noticeable changes take time to go in effect and require many people working together towards a common goal.

Interestingly, Schuldt mentions that "people in industrialized nations tend to perceive climate change as a distant problem, both geographically and temporally, which can dampen fear and other emotional responses that motivate efforts to mitigate climate change". So even being in an industrialized country with the resources, information, and education about climate change, it is still hard to grasp the seriousness of the issue.

One possible way to solve this - providing an emotional response that can motivate people to act on climate change - is using VR. Even deeply rooted attitudes and biases can be changed with the powerful immersion that VR provides. In a study regarding virtual race transformations, the light-skinned Caucasian participants were embodied in a virtual dark-skinned body. Their implicit racial bias was significantly reduced - regardless of the initial racial attitudes or empathy. (Lara Maister et al., 2013)[9] The participants in a similar study expressed greater mimicry with their virtual counterparts of the same skin color, regardless of the actual skin color of the participant. (Béatrice S. Hasler et al, 2017) [10] This validates the notion that despite previously having firm beliefs regarding a topic, it is certainly possible to adjust or shift said notion.

A good example of combining climate change and VR is a study from Stanford where they explored how one could use VR to facilitate learning about Ocean Acidification. A narrator explains the concept of ocean acidification and how the increase of CO2 from climate change allows the molecules to combine with H20 to form carbonic acid. The player is then placed in the water as a scuba diver and discovers that there are many species affected by this. Lastly, the narrator explains how you can how to learn more about the topic and help support ocean acidification research. This study will be examined more thoroughly in the related work of chapter 4.

1.3 Facilitating learning about cultural heritage

Throughout history, many buildings, monuments, and other great structures of cultural importance have been destroyed due to fire. In 2018, Brazil's National Museum was devastated, leaving invaluable artifacts in the ashes; hundreds of Egyptian artifacts, ancient fossils, millions of specimens, and even audio recordings of now-lost indigenous languages were destroyed. [11] An even more recent event is the fire in Notre-Dame de Paris, where a structure fire beneath the roof broke out on April 15, 2019. [12] The interior skeleton of the famous cathedral was made entirely of wood from the 12th century, and this area, commonly nicknamed "the forest", allowed the fire to spread quickly throughout the old building. Luckily, much of the artwork survived the fire and was rescued, such as the world-famous stained-glass rose windows, the Tunic of St. Louis, or the Crown of Thorns. [13] The unfortunate fire in Paris was just one example of the many heritage sites that are not prepared for such events. The United Nations Educational, Scientific and Cultural Organization (UNESCO), writes that "many World Heritage properties do not have any established policy, plan or process for managing, i.e. reducing risks associated with disasters [...]. As a result, hundreds of sites are critically exposed to potential hazards, while communities worldwide are not harnessing the full potential of their heritage, both tangible and intangible, for reducing disaster risk." [14]

Protecting these historic buildings is an important part of preserving the cultural heritage and the application created in this report will provide an opportunity for players to learn about the history and preservation of such a building - Nidarosdomen, the romanesque and gothic cathedral in Trondheim. The users will also be able to experience in VR how a real fire would enfold in Nidarosdomen and attempt to take it out.

Nidarosdomen actually has a long history of restorations after unfortunate fires, weathering and decay throughout its lifetime. The planned expansion in the 14th century was put to an end with a fire in 1328, with another fire in 1432 that brought more damage to the cathedral. The third fire in 1531 became a great catastrophe, and since 1537, only the eastern half of the cathedral was roofed again and taken to use. (Øystein Ekroll, 2015) [15] In 1708, the whole cathedral burned down except for the stone walls, and again in 1719, there was another fire from a lightning strike.

With the creation of the Norwegian constitution in 1814 - which stated that the king of Norway should be crowned in the cathedral of Trondheim - restoration work was deemed necessary. After many years of planning and budgeting, the much-needed restoration finally began in 1869 with architect H.E. Schrimer leading the work. (Øystein Ekroll, 2015) [16] The official restoration work was completed in 2001, more than 130 years after it began, however, the restoration is now considered an ongoing process and continues to this day lead by the Nidaros Cathedral Restoration Workshop (NDR).

1.3.1 Cultural heritage and VR

"Virtual heritage" is the term coined to describe the combination of virtual reality technology with cultural heritage content. One of the earliest examples of virtual heritage is the reconstruction of Dudley Castle in a museum, opened by Queen Elizabeth II in 1994. (Boland et al., 1996) [17] The installation was a virtual reality tour where the participant could move one of two circular buttons to navigate the 3D reconstruction of the castle. Some mark this as the starting point for using VR to present cultural heritage content to the public. Following this, many other museums started similar exhibits featuring virtual experiences of important cultural heritage sites. The University of Columbia's Computer Graphics and User Interfaces Lab was one of the first to develop an application using mobile AR. (Feiner et al., 1997) [18] The aim was to explore the urban environment (i.e., heritage tours around the university), and the participants were carrying big backpacks with portable computers strapped on, wearing bulky HMDs to experience this. The application would overlay 3D models of the buildings that were present before the university was built (e.g., the Bloomingdale Asylum) at its original location. Today, most museums feature some form of XR content to easier demonstrate factual content to the public.

To digitally preserve the many inaccessible cultural artifacts, and make them more readily available for the public, the EU, together with a number of associated partners, has started the Digiart project. [19] They will be using drones to capture 3D scans of sites (e.g., caves) that are difficult for humans to enter without risking damage to the ground or the scientists themselves. These scans will form the basis for several databases that can compare objects and match related artifacts. The scans will also be used to

create interactive XR experiences for the public so they can enjoy cultural heritage sites that would typically be restricted to authorized scientists only.

FIGURE 1.3: The fire department in Trondheim has regular exercises in Nidarosdomen to prepare for a potential fire. Photo: Trondheim Brann- og redningstjeneste (TBRT)

1.4 Research goal

The goal of this research paper is to examine how VR can be used to promote learning and raise awareness about climate change and cultural heritage preservation. There are already many existing VR applications regarding climate change and heritage preservation separately, however, little is found combining these issues in one application. The report from KA indicated that the issues are related to each other and present in Norway's churches, and this research paper will couple them in one standalone application with Nidarosdomen as the environment. The paper will consider how the immersion of VR combined with the Virtuix Omni (Omnidirectional treadmill simulator for virtual reality games explained in Chapter 2) will affect the player's knowledge and awareness of climate change and cultural heritage preservation. Heuristics for game design will be studied and applied together with a model for evaluating player enjoyment in games, (Sweetser et al., 2005)[20] and game theory for how to make a game fun and interesting.(Katherine Isbister, 2008) [21] An existing application for rising sea level in Trondheim (explained in Chapter 4) will be used as part of the semester project for an evaluation and to determine what improvements can be made. These improvements will form the requirements for a new application focusing on fire in VR. The game will consist of two different modes:

1. **Climate change:** The player will watch an introductory movie regarding climate change and a tutorial of how to play the game. [1] After this, the player is placed in an area close to Nidarosdomen, where a fire has started. The aim of the game is to take out the fire before the health points run out.

2. **Heritage preservation:** The player will watch an introductory movie regarding heritage preservation and a tutorial of how to play the game.[2] After this, the player is placed close to Nidarosdomen, and the church itself is on fire. The aim of the game is to take out the fire before the health points run out.

1.5 Research questions

The following are the research questions for this report:

R1: Using the feedback from the Climate Quest application and related game theory, what are the requirements for a new module with fire in Trondheim? Specifically focusing on the theory of game design and criteria such as the current usability, realism, engagement, and immersion of the application.

R2: How can VR together with the Virtuix Omni be utilized to raise awareness about climate change? Specifically looking at forest fires and how climate change is increasing the amount and intensity of fires around the world.

R3: How can VR together with the Virtuix Omni be utilized to raise awareness about heritage preservation? Specifically looking at maintenance as well as safety measures taken to prevent a fire from starting.

1.6 Videos

There are several videos presented in this thesis, both for the introductory videos and for the gameplay. The YouTube URLs are shortened to make them easier to type in, however, the footnotes remain the same with the full links to the videos. Below follows a table with the video links and descriptions.

[1] https://www.youtube.com/watch?v=4zcerplyE1c
[2] https://www.youtube.com/watch?v=oCWLajGucio

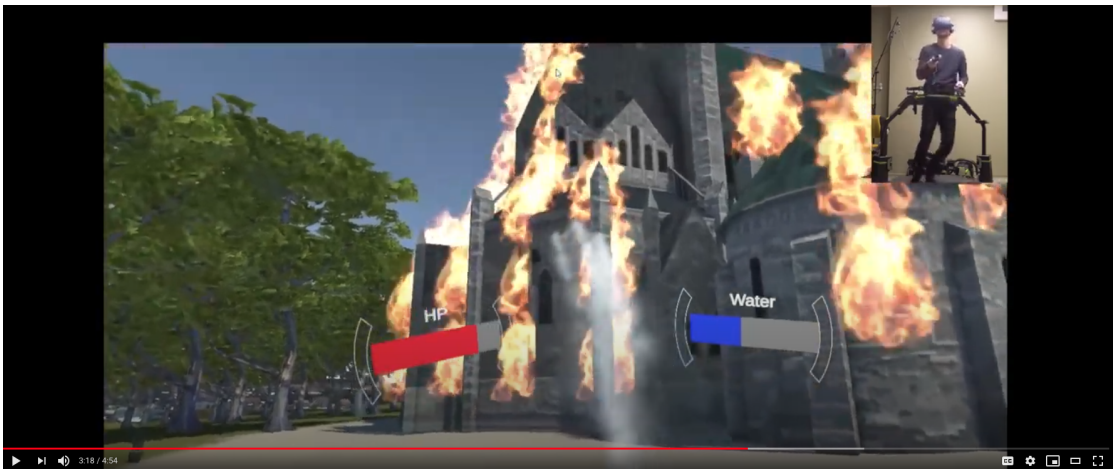


FIGURE 1.4: Video of the gameplay with an overlay of the player player using the VR equipment and Virtuix Omni. (Source: http://tiny.cc/gameplaych)

Description	**URL**
Gameplay of both modules: climate change and cultural heritage	http://tiny.cc/gameplayboth
Gameplay of the cultural heritage module with explanatory text. Used for the second survey	http://tiny.cc/gameplaych
Introductory video and tutorial for climate change (indluced in the gameplay)	http://tiny.cc/tutorialcc
Introductory video and tutorial for cultural heritage (indluced in the gameplay)	http://tiny.cc/tutorialch

TABLE 1.1: Videos used in the thesis with the description and URLs for each. All videos are hosted on YouTube and the links are shortened with tiny.cc.

Chapter 2

Method

This thesis is following an iterative process with testing and improvements made incrementally throughout the project. Literature research has been conducted throughout the semester to form the theory, method and background for this paper. Questionnaires, interviews and observations have established the basis for the data used in the project, following the recommendations from Oates' book "Researching information systems and computing" (Oates et al, 2006) [22].

2.1 Thesis structure

After the introduction and this chapter regarding the method, a chapter with background theory about VR, Virtuix Omni, and game design theory is presented. This will ensure that the reader has the required background knowledge about the topic. The game design theory regarding engagement and motivation will face as a foundation for the subsequent empirical studies. Chapter 4 will be consist of related work and present a description of a VR experience in Trondheim where the sea level is rising. As a part of the semester project, testing this existing application will be done in empirical studies, which will give valuable data for future improvements. These studies will consist of user testing, questionnaires, interviews, and observations and will be part of chapter 5. An evaluation of this application by using the theory from chapter 3 will be conducted in chapter 6 and will form the basis for the requirements for the implementation phase. Chapter 7 will concern the final application and implementation and after developing

prototypes for the new application, new empirical studies will be conducted for this application. The method for the studies will be presented in chapter 8 and the results will be presented in chapter 9 with a discussion of the findings following thereafter in chapter 10. Lastly, a conclusion will complete the thesis in chapter 11.

2.2 Data generation

The data will be collected mostly through visitors of the IMTEL VR Lab at NTNU Dragvoll. These participants will try out the existing application as well as the new prototypes, and give their feedback through questionnaires and interviews. Other observations, interviews and/or informal conversations will be written down as well. The project is part of a combined reporting to the Norwegian Centre for Research Data (NSD) from the IMTEL lab. Particular questionnaires or observations will be conducted for people with additional knowledge of a subject to utilize their expertise. The questionnaires will be given after the participant has tried the application and will be done using Google Forms and Microsoft Forms. Privacy forms will be filled when required and attached in the appendix.

2.3 Likert scale

Most of the questions that are part of the questionnaires will be using the Likert scale. (Likert, 1932)[23] With a Likert scale, participants respond on a symmetric agree-disagree scale for an array of statements. There are several different Likert scales commonly used for empirical studies. This report will utilize the five-point Likert scale illustrated below:

1. Strongly agree
2. Agree
3. Neutral
4. Disagree
5. Strongly disagree

Using the Likert scale more accurately captures the intensity of the feelings for a given statement, compared to a simple true/false or agree/disagree fact.

2.4 Evaluation of results

2.4.1 Questionnaires

The data from the first questionnaires from the semester project (background) will be used to determine what features that could be improved on the existing application and the results will be examined to evaluate the immersion, realism, and educational use of the application. (specifically when comparing it to existing theories for engagement, motivation, and immersion). The combination of this empirical data and theoretical analysis from research literature will form the basis for the requirements of the application. The subsequent questionnaires will be conducted *after* development of the new application has started and will be used to establish further improvements to the application being developed.

2.4.2 Interviews

The interviews are mostly structured interviews with questions prepared beforehand and the signed consent forms are in the appendix. The results are evaluated using thematic analysis with the same method described in the paper by Virginia Braun and Victoria Clarke (2006) [24].

2.4.2.1 Thematic analysis

Thematic analysis is a method for analyzing qualitative data. Thematic analysis is often used to evaluate the results of an interview in a more structured manner and the six steps commonly used are:

1. Familiarization
2. Coding
3. Generating themes

4. Review themes
5. Defining and naming themes
6. Writing up

The first step is to familiarize yourself with the data. For interviews, this includes going through the notes of the interview, transcribing it, reading it thoroughly and getting familiar with it. Next up is finding coding in the text. This is done by highlighting phrases or sentences that corresponds to a label or "code" that describes the content. The third step is to then use these codes to generate themes by identifying patterns among them. Eliminating codes and/or combining them is common to do in this step. The fourth step is then to review the themes and make sure they are an accurate representation of the data. Following this, the next step is to define and name the themes, and lastly the final, sixth step is to write up the results of the analysis.

Chapter 3

Theory

Much of the theory is based on the research done in the semester project and is retained in this report.

3.1 Extended Reality (XR)

Extended reality is an umbrella term to describe the combined elements of human-machine interaction with computer-generated environments that either merge the virtual and the physical world or create an entirely new, immersive virtual world. Generally, the term is comprised of three types of realities [25]:

- Virtual Reality (VR)
- Mixed Reality (MR)
- Augmented Reality (AR)

This paper will briefly discuss the three to get an overview of XR and will dive deeper into the specific hardware used for the virtual experience in Trondheim.

3.1.1 Virtual Reality (VR)

Virtual Reality is generally considered to be a fully immersive experience in a simulated digital environment. Using a Head-Mounted-Display (HMD), the user experiences a

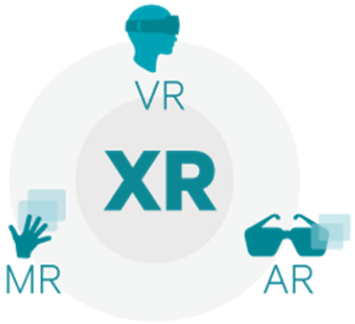


FIGURE 3.1: The three major components related to Extended Reality (XR)

virtual world with a 360-degree view of it. The virtual world moves as the user's head moves, resulting in a feeling of presence in the digital world, and the realism is often further improved with sound and the ability to interact with objects or elements in the world. Although the most common type of VR today is definitely through HMD, there are several other methods to experience Virtual Reality. Specially designed rooms, for example, with multiple large screens, can also serve the same purpose. Simulations for different vehicles and/or machines are also very common where the driver is physically seated within the machine connected to a big screen. The motion feedback, together with the audio and visual cues, gives the participant the impression of actually operating the machine. This removes the danger of operating the machine in real life and the consequences that might follow from a mistake, miscalculation, or human error. Other typical applications for VR include education, military, astronaut training, flight simulators, miner training, architectural design, driver training, bridge inspection, and much more.

3.1.2 Augmented Reality (AR)

Instead of replacing the real world completely, Augmented Reality seeks to add additional computer-generated perceptual information on top of the real world. Comparing it to VR with an HMD, it can be described as "a form of virtual reality where the participant's head-mounted display is transparent." (Hsin-Kai Wu et al., 2012) [26] AR can be represented by three distinct characteristics: [26]

- Combination of real and virtual worlds
- Real-time interaction

- Accurate 3D registration of virtual and real objects

The information presented can be in the form of visual overlays, haptic feedback, or other sensory projections. With the help of different AR technologies, the information about the surrounding real world of the user becomes interactive and digitally manipulated. AR has recently seen a steady upward trend with the rise of smartphones capable of mapping out the world in real-time through the smartphone's camera and place objects into the real world. A classic example of this is the success of the AR-game Pokemon GO, where the players can catch Pokemons seemingly existing in the real world due to AR.

3.1.3 Mixed Reality (MR)

The terms Augmented Reality and Mixed Reality are often confused and sometimes used interchangeably. However, while Augmented Reality is usually seen as Virtual objects that overlay the real world, Mixed Reality not just overlays, but anchors virtual objects to the real world. Using the example above with Pokemon Go, if you physically move closer to the Pokemon it moves away from you. In MR, the Pokemon would be anchored, and as you move closer, the Pokemon would get bigger, and it would seem as it is just standing there. Moving around and seeing it from different angles would provide a similar effect. It is also often possible to interact with the objects naturally using your hands, further minimizing the gap between the real world and the virtual world.

3.2 Hardware

To experience XR, different hardware is required. In this section, we will discuss some of the hardware that is commonly used for the various XR applications.

3.2.1 Head-mounted Display (HMD)

Most XR applications are operated using a head-mounted display. Naturally, from the name, an HMD is a display device that is mounted on your head. Typically it

consists of two small displays, one for each eye (binocular), although single-eye headsets (monocular) also exist. Using two displays instead of one gives the user a sense of depth and thereby increases the realism. Most HMDs also includes a tracking device so that when the user moves his head, the view displayed for the user moves along with it. Additionally, it is common to incorporate dual speakers that fit around the ears to provide a surround sound for better immersion.

3.2.1.1 Oculus Rift

Perhaps the most famous example of an HMD is the Oculus Rift. Announced in 2012 as "Rift", the headset aimed to provide VR headset easily accessible for developers and consumers. After a successful Kickstarter campaign [27], two versions of the headset were released; Oculus VR DK1 (Development Kit 1) and Oculus VR DK2 (Development Kit 2). The first version was released to backers in March 2013 with the intent to have developers make content for the subsequent consumer release. The headset boasted a field of view (FOV) of 110 degrees, which was more than double the FOV of the HMDs from other companies. The resolution was 1280x800 (16:10 aspect ratio), which corresponds to 640x800 per eye (4:5 aspect ratio). The DK2 was released in July 2014 and improved upon the feedback generated from DK1. The most noticeable feedback was from the poor resolution of the display, and this was incrementally improved and tested in the two unreleased "HD" and "Crystal Cove" prototypes before finally being incorporated into the DK2. The second release of the development kit had a higher-resolution (960x1080 per eye) low-persistence OLED display, higher refresh rate, positional tracking, and you no longer needed to have an external control box. The version that was finally released to the consumers was the Oculus Rift CV1 (Consumer Version 1). It was released in March 2016 and was an improvement on the previous versions with better resolution (1080x1200 resolution running at 90 Hz), integrated audio and more focus on the aesthetics due to it being released to a broader public. The latest version of the Oculus VR headset is the Oculus Rift S. It has a 2,560x1,440 LCD running at 80Hz with the new dominant feature being the tracks the position of itself and its controllers in 3D space using Oculus Insight. It uses a combination of 5 cameras, infrared sensors, accelerometers, and computer vision to achieve this.

FIGURE 3.2: The Oculus Rift CV1 (Consumer Version 1), a virtual reality headset made by Oculus VR and released in 2016. Source: [28]

3.2.1.2 HTC Vive

Following the success of Oculus, HTC partnered up with Valve to create its own VR headset. The headset was named "HTC Vive" and was released in April 2016. The headset has two OLED screens, each with a resolution of 1080x1200 (2160x1200 combined) running at a refresh rate of 90Hz with a 110-degree FOV. It includes a front-facing camera which can be used to see what's in front of you without taking off the headset, and also act as a safety feature. The HTC Vive is also shipped with controllers that contain 24 infrared sensors that can keep track of where the controllers are using the Vive Base Stations (also called Lighthouse Tracking System). This tracking system creates a virtual space of up to 5x5m and accurately tracks the position of the headset and the controllers using infrared pulses at 60 pulses per second. A pro version of the headset was released in January 2018 and featured a higher resolution display of 1440x1600 (2880x1600 combined), a second outward-facing camera, headphones, and a microphone for noise canceling.[29] This is the headset that was used in the previous work (Chapter 3) and will be used for the continued work of the master's thesis.

FIGURE 3.3: The HTC Vive released in 2016, Source: [30]

3.2.2 Virtuix Omni

The Virtuix Omni is an omnidirectional treadmill, meaning you can move in any direction allowing you unencumbered movement in a virtual space. [**virtuix-Omni-2019**] It works by tracking the movement of the feet as the player's feet slide on the slippery surface of the Virtuix Omni. The player wears special made low-friction shoes (above or instead of regular shoes) and these shoes slide more easily on the surface of the device. A sensor is attached to each shoe making it possible to track a person's position, the length of their stride, and how fast they are moving. For safety, the player wears a harness around the waist that is connected to the Virtuix Omni, which is able to rotate 360 degrees. The device is compatible with HTC Vive and allows players to walk, run, and experience virtual spaces freely in a variety of games. The project was initially funded through a Kickstarter campaign, reaching the top 10 most funded projects at the time, but has now raised over $20 million from private investors and institutions. Kickstarters began receiving their device around January 2017; however, today, the Virtuix Omni is only available through business inquires. Luckily, the IMTEL VR Lab at Dragvoll acquired one, and the game developed in the previous work (Chapter 3) uses the Virtuix Omni to move around freely in Trondheim city.

FIGURE 3.4: Virtuix Omni

3.2.3 Cyberith Virtualizer

Another omnidirectional treadmill is the Cyberith Virtualizer. [31] It functions similarly to that of the Omni and provides the player the ability to experience walking and running in VR in 360 degrees of freedom. The project was started as a Kickstarter campaign on the 23. of July 2014 and was successfully funded at $361.452. The first commercial launch of the Virtualizer Treadmill was in 2016, and the second generation was launched to business customers in March 2019. The Virtualizer ELITE 2 features a motion platform with an inclination that makes it possible to walk uphill in VR and which optimizes the angle according to the movement speed of the player. The device can also register the height of the player's hips, which can determine the scale of the avatar as well as register the vertical movement of the player. An application in the related work chapter (Chapter 3) uses the Cyberith Virtualizer treadmill to simulate evacuation in a tunnel.

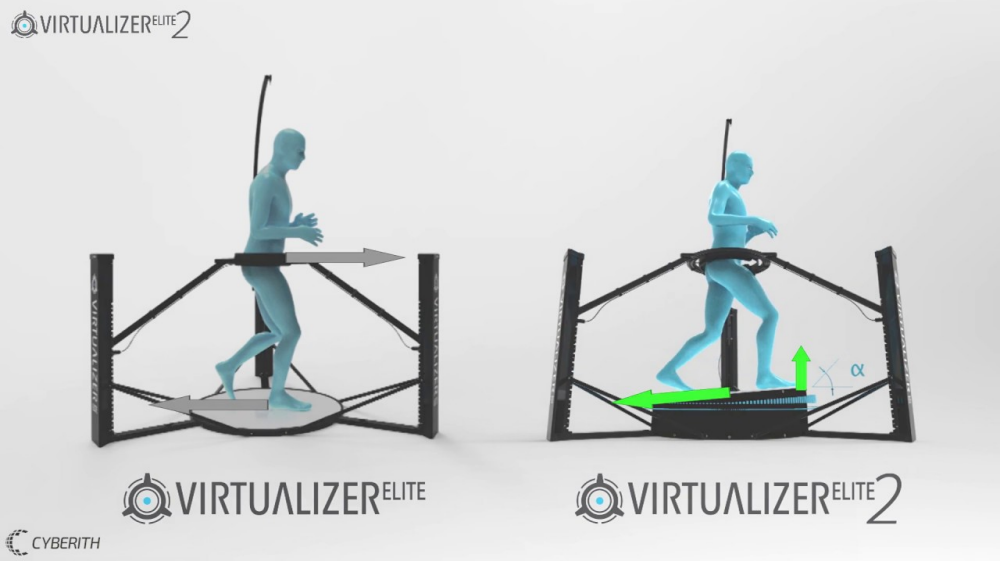


FIGURE 3.5: The Virtuilizer Elite and the Virtuilizer Elite 2 featuring an option for inclined movement

3.3 Game theory

3.3.1 What makes a game fun and engaging?

People play games to explore a new experience, to feel specific emotions, and to have fun with friends. To create a game that is engaging and fun to play, it needs to release

certain emotions to keep the player captivated and immersed in the game. According to Nicole Lazzaro, an award-winning designer, and expert on emotion and games, there are four different keys to unlocking emotions in games: Hard fun, Easy Fun, Serious Fun, and People Fun. (Isbister & Schaffer, 2008)[21]

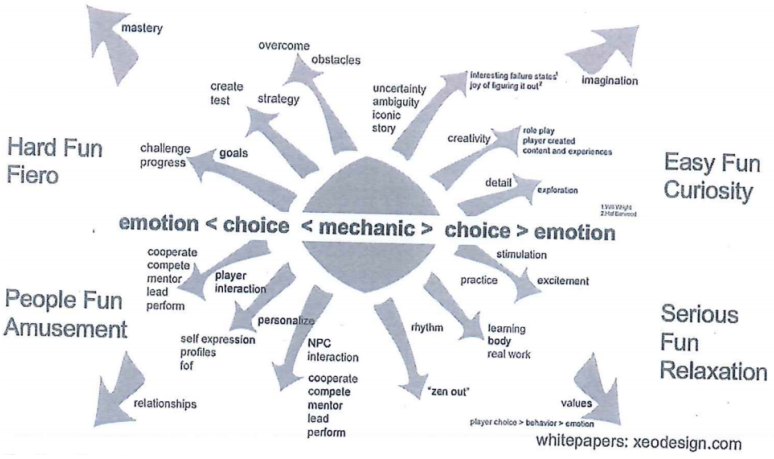


FIGURE 3.6: The four fun keys as described by Lazzaro

This model is created by watching the emotions of people as they played different types of games. Players tended to enjoy games that combined the different fun keys, and the best selling games would often have three out of the four. To keep the game interesting, players often move between these styles of play.

3.3.1.1 Hard Fun

Some games are so difficult that it feels almost impossible until you finally manage to complete the task. These games are utilizing Hard Fun to keep the player interested. In Hard Fun, the player needs to overcome obstacles and score points, and game mechanics such as bosses, power-ups, and puzzles maximizes this.

Hard fun encapsulates three different emotions: frustration, relief, and fiero. The latter being an Italian word because Lazzaro feels that the English language lacks a proper word for it. It literally means ”personal triumph over adversity.” It can only be described by the feeling you get when you eventually manage to defeat the tough boss monster or when you win the Grand Prix and jump out of your chair screaming, ”Yes, finally!”.

To be able to feel fiero, one must first experience frustration. One must lose a few times, or be unable to solve a puzzle for a while, before ultimately feeling fiero as one

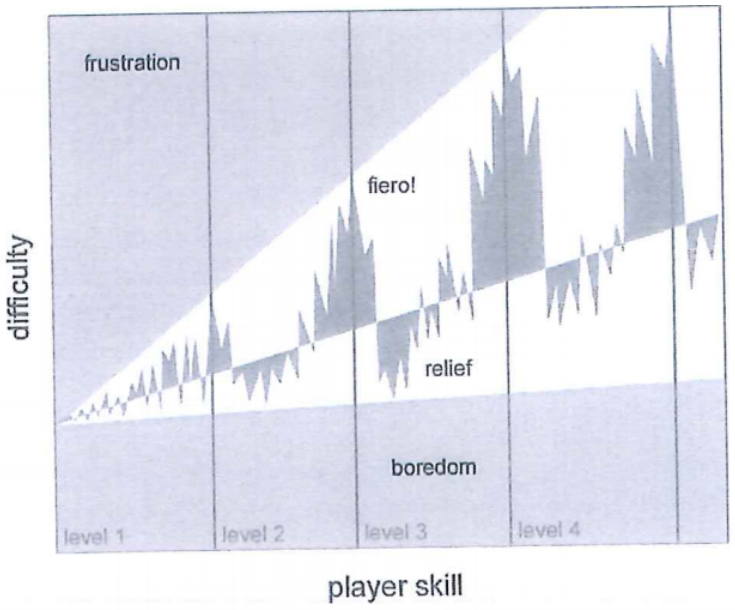


FIGURE 3.7: A typical level progression of Hard Fun. The challenges gets harder as the player skill progresses. The challenge is to keep the game between the fine line of frustration and boredom.

accomplishes the task. This is then subsequently followed with the emotion of relief as the player calms down. These three emotions cycle as the player progresses through the game. Often, the challenges get harder and harder, and thereby the relief also feels more satisfying every time.

3.3.1.2 Easy Fun

Easy fun is when a game offer interactions outside of the difficult challenges of the Hard Fun. These type of interactions encourages exploration and curiosity in a player and is often an escape from the ”main” challenges of the game. A good example of this is Grand Theft Auto (GTA) where there is a storyline to follow, but you can ultimately do whatever you want and just explore the city.

This freedom in the game provides the player with a sense of curiosity and focuses the player on a positive emotion - as opposed to frustration. The curiosity and exploration often lead to an unexpected surprise, which gives the player the emotion of wonder or awe. Relief then completes the cycle, and the player goes back to curiosity with more exploration or goes back to the main challenge of the game.

3.3.1.3 Serious Fun

Serious Fun aims to provide players with a purpose or value outside of the game itself. Think after a long day at work how rewarding it is to relax with a fun game. Players want to change how they think, feel, behave, or to accomplish actual real work. They can use the game to gain valuable skills, to learn something new, or simply to feel better emotionally. Serious Fun games can create emotions for benefits outside of the game, such as a player wanting to lose weight playing Dance Dance Revolution, or to get smarter with the game Brain Age.

Without any form of Serious Fun, the game can sometimes feel like a waste of time. The enjoyment can fade away as the player realizes that the game has little or no impact on one's life, and only provides a less desirable mental state after finishing - comparable to the feeling after watching too much TV. So there are numerous emotions of Serious Fun, but most notably is being relaxed and being excited. Relaxing is tied to how the player makes them feel, while excitement is related to how a player wants to change themselves or learn something new.

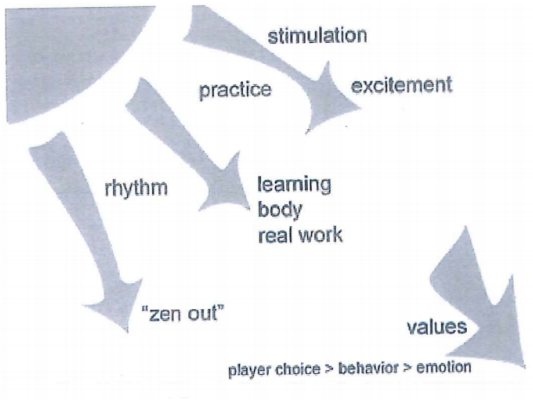


FIGURE 3.8: Players value how a game makes them feel and how they acquire new values that help them change themselves for the better.

3.3.1.4 People Fun

Lastly, there is People Fun, where the focus is playing together with friends or other people and the emotions that it creates. The interactions between players can be through communicating face-to-face in the same room, chatting online, calling, or through the game itself. The players in the game cooperate to fulfill a specific task or to explore and learn together. They inspire, elevate, and excite each other, and this cooperation

between players generates strong feelings of trust, companionship, and form a social connection.

The most obvious emotion in People Fun is amusement, where you simply have fun playing games with your friends, tell jokes, laugh and bond socially through the game. This amusement, in turn, creates social bonding, which again leads to more player interaction. The cycle repeats itself.

3.3.2 What makes things fun to learn?

While playing games can be fun and engaging, it can also simultaneously be educating - as seen with the Serious Fun in the previous section. Thomas W. Malone defined in his paper three essential heuristics for designing fun, instructional games. (Malone, Thomas W., 1980) [32]:

- Challenge
- Fantasy
- Curiosity

3.3.2.1 Challenge

An educational game must have some sort of goal for the player to achieve. The player must know whether they are getting close to the goal, and it should be a compelling goal for the player to feel engaged. If the player was either certain to win or lose, the game would be boring - it needs some sort of uncertain outcome, and there are several ways to achieve this. Many games have *hidden information* for the player to find and explore to provoke curiosity and challenge in the game. Some introduce *randomness* to make the player more on the edge of its surroundings, and most games provide *variable difficulty level* to cater to the player's skills and experience.

3.3.2.2 Fantasy

To make an educational game more fun, a fantasy element can be applied. Take the existing "curriculum" you want to teach and coat it with a game in which the player

progresses toward some fantasy goal or avoids some fantasy catastrophe. Malone defines two different types of fantasies: Intrinsic fantasy and extrinsic fantasy. In both cases, the fantasy depends on the use of the skill; however, with the intrinsic fantasy, the skill also depends on the fantasy.

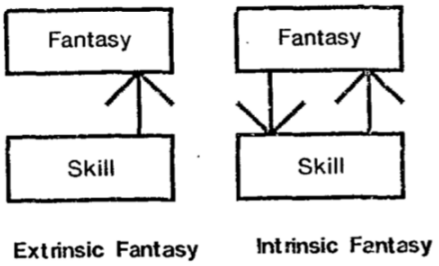


Figure 1. Logical dependencies in extrinsic and intrinsic fantasies

FIGURE 3.9: Extrinsic fantasies are when the fantasy depends on the skill, while with intrinsic fantasies, the skill also depends on the fantasy.

An example of an intrinsic fantasy is a game where elementary students are learning about fractions through a game of darts. Three balloons are placed randomly on a number line, and the students guess where they are by typing in mixed numbers. The dart then shoots across the screen and hits the number line; if it's correct, the balloon pops. If not, the dart remains on the same spot, and the student can try again. The skill of estimating distances is applied to the fantasy world of shooting darts, and the skills affect the fantasy. It also does not only depend on whether the skill is used correctly, but it also depends on how its use is different from the correct use (if you miss you see where you hit and can adjust based on that)

Malone believes that in most cases, intrinsic fantasies are more instructional than extrinsic fantasies because it is more closely related to the real world, and it can indicate how you would use the skill in the real world too. An interesting observation Malone made regarding the use of a catastrophe fantasy, is that the player sometimes *tries* to do the wrong thing in order to see what the outcome of the catastrophe is.

3.3.2.3 Curiosity

Curiosity can be divided into two types: sensory curiosity and cognitive curiosity. Sensory curiosity is the use of audio and visual effects to create an exciting and engaging

environment that is compelling for the player to explore. These effects can be used to enhance the fantasy in the game, as a reward, as a representation for information, or simply as decoration to reinforce a player's interest in the game. The cognitive curiosity is accomplished by leaving out just enough information for the player to be interested and motivated to continue exploring. A good example of this in the real-life would be to read all but the last chapter of a murder novel - and already having thoughts on who the killer might be - but still wanting to finish the last chapter to confirm it. The same can be applied in computer games by purposely leaving out certain information, or hide some information, to spark the player's curiosity.

3.3.3 Gameflow - evaluating player enjoyment in games

There have been many theories that aim to analyze and understand enjoyment in games in terms of *one* specific aspect or concept. However, Sweetser and Wyeth describe in their paper regarding gameflow (Sweetser et al., 2005) [20] a model for evaluating computer games using *nine* aspects. The theory is based upon the existing theory of Flow from Csikszentmihalyi (1990) [33] and adapted to analyze the enjoyment of games instead of general experiences. The model of flow from Csikszentmihalyi is based on extensive research over dozens of years and with strong data from several thousand respondents to interviews, questionnaires, and other data. His model of flow consists of eight elements:

1. A task that can be completed
2. The ability to concentrate on the task
3. That concentration is possible because the task has clear goals
4. That concentration is possible because the task provides immediate feedback
5. The ability to exercise a sense of control over actions
6. A deep but effortless involvement that removes awareness of the frustrations of everyday life
7. Concern for self disappears, but a sense of self emerges stronger afterward
8. The sense of the duration of time is altered.

There is also an important precursor to a flow experience mentioned by Csikszentmihalyi. The precursor is "a match between the person's skills and the challenges associated with the task, with both being over a certain level." [20]

These elements of flow can be mapped into what is defined as gameflow. The first element in the flow is not directly linked to the gameflow since the task that can be completed is the game itself; however, the rest of the elements are closely related. Table 2.1 shows this mapping from the existing theory of flow to games literature, and below are explanations of each of these elements.

Games Literature	Flow
The Game	A task that can be completed (1)
Concentration	Ability to concentrate on the task (2)
Challenge Player Skills	Perceived skills should match challenges and both must exceed a certain threshold (precursor)
Control	Allowed to exercise a sense of control over actions (5)
Clear goals	The task has clear goals (3)
Feedback	The task provides immediate feedback (4)
Immersion	Deep but effortless involvement, reduced concern for self and sense of time (6, 7, 8)
Social Interaction	N/A

TABLE 3.1: Mapping from the existing theory of Flow to Games Literature

3.3.3.1 Concentration

Concentration in games is related to how much attention a player gives to the game and how well the player concentrates on the given task within the game itself. To achieve this, games must quickly grab the player's attention and keep it for as long as possible. This means that the workload has to be balanced to the player's perceptual, cognitive, and memory limits. Lastly, the tasks should feel relevant and important to the goal of the game, and the players shouldn't be distracted from tasks they want to concentrate on.

3.3.3.2 Challenge

To keep the game interesting, it has to be challenging enough. However, it can't be so challenging that players immediately give up - the level of challenge should match the player's skill level. Throughout the game, the challenges should increase in difficulty

and quantity. It is also essential to keep the challenges relevant to the progress of the game and the skill progression of the player. Therefore, players should be given new and exciting challenges at an appropriate pace in the game.

3.3.3.3 Player skills

This section is closely related to the point above - that the games must support a player's skill development throughout the game. Learning the game should be easy and fun and not require a manual. This often includes an interactive tutorial or initial, more manageable levels to familiarize the player with the game's aspects, interactivity, and controls. As the players progress through the game, the mechanics of the game should become more difficult - it is impossible and boring to learn everything at once. Finally, it is essential to reward the player on their progression of the skills through special awards or tokens within the game.

3.3.3.4 Control

Players need to feel a sense of control in the game. They need to feel like they can control their character(s) movements and interactions. This requires the input controllers to be responsive to a player's actions and that the player knows how to use the input controllers to pause, exit, or start the game. If a player makes a mistake in the game, the game should assist the player with help to recover from the mistake and not punish the player so that he/she loses interest. The players should also feel like their actions in the game matter and that the virtual world inside the game is changed as a result of the player's actions. They should not feel obligated to follow a predetermined strategy to complete the tasks but should be able to freely come up with new plans and strategies.

3.3.3.5 Clear goals

The game's goals need to be clear and concise and presented at an early stage of the game, so the player has an overview of what is expected throughout the game. It is also an advantage to be able to know the progression of the goals as you get closer to reaching them. New goals need to be presented at the appropriate time.

3.3.3.6 Feedback

Expanding from the point above, the goals need to be visible to the player for them to track their progress towards them. Feedback of the player's actions needs to be shown, and the environment should react appropriately to these actions. In addition to this, players should be able to see their score that's accumulated from accomplishing the goals or tasks in the game.

3.3.3.7 Immersion

An important aspect of the game's enjoyment is how immersed a player is in the game. The immersion can be strengthened by making the players feel more emotionally involved in the game. They should become less aware of their surroundings and worry less about their daily tasks. Instead, they should be focused and concentrated on the game and the tasks within the fictional world. The players should even experience an altered sense of time when being fully immersed in the game.

3.3.3.8 Social Interaction

Lastly, a successful game needs to have some sort of social interaction with other players. The game could support competition or cooperation between players - or both. Social interaction creates strong bonds between players, and they feel more invested in the game. Usually, the interactions are supported inside the game through an in-game chat function or similar functionality. As mentioned in the section about the four fun keys, the players often form communities with inside jokes that last outside the game as well.

3.4 User Experience Questionnaire

User Experience (UX) can be difficult to measure, and many attempts have been made to construct a framework to determine how good a products' user experience is. One such framework is the "User Experience Questionnaire" (UEQ) developed by Bettina Laugwitz, Theo Held, and Martin Schrepp in 2008. [34]. Concluding two brainstorm sessions with fifteen SAP usability experts, an initial list of 221 descriptive adjectives was

formulated. This list was narrowed down by seven usability experts who individually extracted the ”top 25” items on the list, which resulted in 80 remaining adjectives. Finally, six UEQ scales and the items representing each scale were extracted from this data set by principal component analysis. The result was a 26-item questionnaire with items represented by two terms with opposite meanings. The items are scaled from -3 to 3 on a 7-point scale, where +3 is the most positive response and -3 the most negative response. The questionnaire measures six scales: [35]

- **Attractiveness:** Overall impression of the product. Do users like or dislike the product?
- **Perspicuity:** Is it easy to learn how to use the product?
- **Efficiency:** Can users solve their tasks without unnecessary effort?
- **Dependability:** Does the user feel in control of the interaction?
- **Stimulation:** Is it exciting and motivating to use the product?
- **Novelty:** Is the product innovative and creative? Does the product catch the interest of users?

An example of an item is:

attractive o o o o o o o unattractive

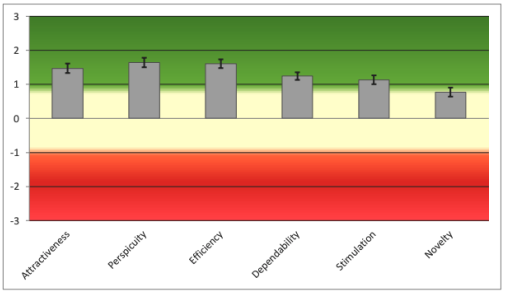


FIGURE 3.10: The product is measured in the six scales on a score from -3 to 3.

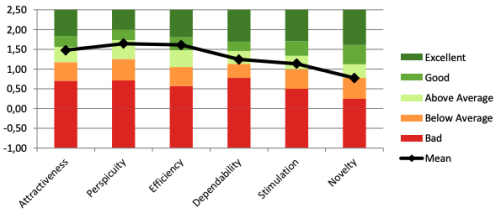


FIGURE 3.11: The results can easily be compared to a benchmark of hundreds of previous products evaluations.

The consistency, as well as the validity of these scales, were tested in 11 usability tests with 144 participants supplemented with an online survey with 722 responses. Using Cronbach’s Alpha, these studies showed a satisfactory high scale consistency and good construct validity of the scales. (Schrepp, 2019) [35]

Despite being a relatively short survey taking roughly 5 minutes to complete, there are specific scenarios where a shorter version is more applicable. In a paper from 2017, three scenarios were outlined where a shorter survey would be beneficial (UEQ-S).(Schrepp et al., 2017) [36] One of these scenarios is when the UEQ is part of a more prominent questionnaire, and including the whole UEQ would make the questionnaire way too big. Therefore, the version used for the first survey for the fire application is this shorter version of the survey. The regular UEQ has a benchmark (which is updated each year) of the six scales using data from hundreds of product evaluations. (Schrepp et al., 2017) [37] The scales are classified into five categories: Excellent, good, above average, below average, and bad. The shorter version, however, allows a rough measurement of higher-level meta-dimensions. This includes pragmatic quality aspects (goal-directed) and hedonic quality aspects (not goal-directed) as well as an overall scale.

Chapter 4

Related work

4.1 Trondheim VR

This project is from the Bachelor's thesis that was written by Simon N. Barak, Benjamin Fimreite, Filip Hagen, Trym E. E. Høgelid, Aleksander M. Karlsson, Maria E. Nylund, and Åsmund Staldvik. (2019) [2]

4.1.1 Intro

The project has two modules with distinct functionalities and use. The first module is a game focused in Trondheim, where the goal is to run around Trondheim shooting targets. Shooting the targets gives points to the player, and these targets can be placed anywhere in Trondheim. There are also signs that the user can read to learn more about Trondheim's buildings and attractions. The other module is a "Climate Quest" game in which the player is placed near "Gamle Bybro" and should run towards a target across the bridge. As time goes on, the sea level in Trondheim rises, and to prevent it, the player has to shoot at certain elements as quickly as possible. In the end, a score is presented with the time elapsed, the number of targets hit as well as the current sea level.

Both modules utilize the Virtuix Omni to move around Trondheim together with the HTC Vive Pro for the VR headset to look around. The Vive Controllers are used to shoot the targets and to see the statistics of the sea level and climate.

4.1.2 Module 1: Shooting targets

This module consists of two parts:

- The game itself
- Quest creator program

The game itself is accessed by selecting from a list of quests. These quests are loaded from *.json* files located in the *Assets* folder and the quest creator program handles the creation of these *.json* files through a user-friendly GUI.

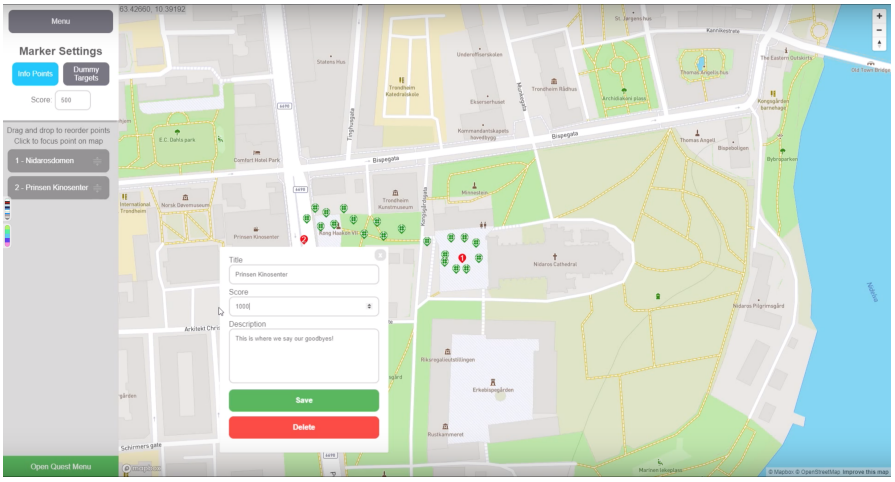


FIGURE 4.1: The process of creating a custom map with dummy targets and information points. This map can later be used with the Virtuix Omni.

When creating a new quest, the user uses sees a map of Trondheim through MapBox can move freely around the city. The user can then put down either an information point or a dummy target with an associated score for each of them. Clicking on the respective button on the sidebar and clicking on the map will place the element on the map. Setting the title, description, or score of the elements is done by clicking on the already placed elements, and deleting them is done in a similar manner. If you want, you can reorder the points on the map in the sidebar.

When playing the game, the user runs around Trondheim shooting dummy targets to increase the score and reads the information points to gather knowledge of the surrounding area.

4.1.3 Module 2: Climate change quest - rising sea level

The second module is focused on the possible effects of climate change in Trondheim - specifically regarding rising sea levels.

FIGURE 4.2: Rising sea level as an effect of climate change in Trondheim. The only way to stop it is to shoot at cars, chimneys and CO2 molecules.

The game starts with a description of the task: Shoot chimneys, cars, and CO2 Molecules to lower the sea level. The sea level rises as time goes on, and the goal is to reach the green target before you drown. Shooting the targets turns them into a more environmentally friendly version, as seen below:

- Chimneys ⇒ Solar panels
- Cars ⇒ Bikes
- CO2 Molecules ⇒ Trees/Plants

The player can keep track of the current sea level and climate by looking at the controllers in VR. At the end of the game, the player presses a button to finish. This presents a dialog with the elapsed time, the current sea level, and how many targets you hit.

4.2 VR Field Trips - Ocean Acidification

A study from Stanford explored how one could use VR to facilitate learning about Ocean Acidification.(Markowitz et al., 2018) [1] Through 4 studies with over 270 participants,

they investigated how immersive VR could be used to teach people about the effects climate change has on ocean acidification. The first study allowed students to go on two scuba diving field trips as well as an immersive VR session. In the VR session, the participants would embody a coral and would see the effects of ocean acidification. In the second study, half of the participants saw themselves as coral, while the other half as scuba divers on the ocean floor. They wanted to see if becoming someone, or something would increase the learning gain. This study suggested there was an increase in the learning outcome and the environmental concern - regardless of which avatar the participant embodied. The third study was conducted at the 2016 Tribeca Film Festival and included a total of 488 participants; however, a lot of the data was discarded due to technical reasons, and failure to respond to attitude prompts, which resulted in a sample size of 167 participants. The experience is similar to the one which is publicly available on Steam [1], although the steam version is now updated to include more features. The experience starts on a floating boat, and the participants were then trained to swim underwater and find marine life. They started at an underwater zone and were tasked to count snails, octopi, and eel. After two minutes, they were moved into an acidified zone where there were few or no species, subtly communicating that the species could no longer live in the acidified zone. Throughout the experience, the narrator was explaining the tasks and background information. The fourth and final study considered whether the locomotion techniques affected the knowledge gain. There were two different techniques: (1) swimming by using physical arm movements as gestures, and (2) swimming by using a joystick. The participants were placed in a similar environment as before, with one underwater zone being healthy and one acidic. The study found no significant difference in the learning outcome with the different locomotion techniques.

4.2.1 Ocean Acidification Experience

The experience available on Steam is a little different from the one explained in the paper, and has most likely been updated after its release. The Steam experience starts by showing CO2 molecules coming out of a car while the narrator explains facts about climate change. The participant is then moved to a floating boat where CO2 molecules are visible in the air, and a water molecule is seen in the water in front of the boat.

[1] https://store.steampowered.com/app/409020/ The_Stanford_Ocean_Acidification_Experience/

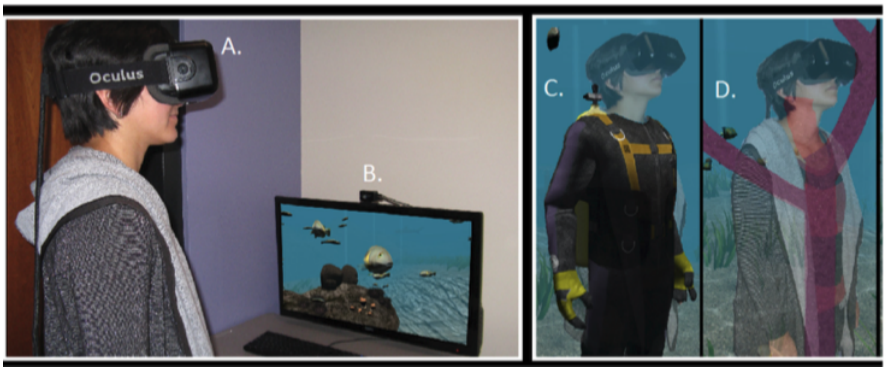


FIGURE 4.3: A and B: Participants wearing the VR headset and experiencing the VR application. C and D: The two forms of embodiment that was tested during the second study: in the form of a scuba diver (C) and a coral reef (D)

The narrator explains ocean acidification by showing the chemical reaction when CO2 combines with H2O to form carbonic acid. After this, the player is placed in the water and is tasked with counting snails by placing flags on them. Like with the other studies, the underwater environment changes to a more acidic one, and the narrator explains that there are no more species left because they are unable to live in such an acidic environment. The experience ends with a zoomed out version of the world where the narrator explains that the "the future of our earth is in your hands" and describes how you can how to learn more and help support ocean acidification research.

FIGURE 4.4: The Stanford Ocean Acidification Experience available on Steam showing how CO2 molecules spread from the exhaust pipe of the car which later is absorbed by the ocean

4.2.2 Results

The study shows that "after an immersive VR experience, people report positive knowledge gain or an interest in learning about the causes and effects of ocean acidification."

(Markowitz et al., 2018) [1] It also proves that complex scientific information can be delivered and taught to young adults through immersive VR and shows that people can learn about complex social and environmental issues when information is brought to them in an immersive format.

4.3 Simulating evacuation in a tunnel

Because training for emergency situations can often be expensive, risky and difficult to replicate, the potential for VR applications to simulate these situations is significant. One such study from 2018 considered the challenge of communication and collaboration between different emergency management (EM) professions, and developed a VR application to simulate an emergency scenario with several characters such as an operations control manager, plant workers, firefighters, police officers, and medics. (Molka-Danielse et al., 2018)[38] The participants could interact with each other, and collaborate on decisions for various dilemmas occurring in a dynamically changing environment.

Another study, by SINTEF in 2018, considers emergency situations in tunnels due to collisions, fires, dangerous liquids, volatile gases, or terrorist activities and how to improve tunnels to be able to handle these situations the best way possible. The study uses a realistic VR model of a 7.3km underwater tunnel with fire extinguishers, emergency telephones, and signs. The participants try out six different scenarios with varying lighting for the exit signs, distance to walk to the exits, and sound effects. Success was measured in the ability to find and open the exit door, choosing the right path to the exit door and the speed of which the participants were walking/running. The players would use the Cyberith Virtualizer to navigate inside the virtual environment. Before the players could move, a priming video was shown of the car entering the tunnel and experiencing a traffic stop with a view of the fire itself and abandoned passenger cars. In some scenarios, the tunnel would be filled with smoke, so the players would have a hard time seeing anything in front of them. The participants were asked to find their way out of the tunnel.

FIGURE 4.5: The tunnel fire

4.3.1 Results

The results show that the distance between the exits affects the time to evacuate. A doubling of distance from 250m to 500m showed a 4x time difference from 2 minutes to 8 minutes. With the longer distances, a lot of the participants also hesitated and turned back, thinking they'd missed the exit. Using sound systems was more efficient than signs with an arrow pointing downwards, indicating that the exit sing was on the other side of the road. Even more effective, though, is to have two exits - one on each side. Continuous guidance lights proved to be very effective, where participants choose the right side and walk significantly faster toward the exit. These results are very interesting for the safety aspect of the future application.

4.4 Experiencing a town of the Middle Ages: An application for the edutainment in cultural heritage

The MediaEvo Project aim to develop a multi-sensory platform for educating students about cultural heritage and medieval history and society. (Maister et al., 2013) [39] The result is an edutainment game where the goal is to experience the everyday life and activities of people living during the Frederick Age (XIII century).

The game is set in the south of Italy in the Salento peninsula in the city of Otranto, an important city in the Middle Ages. The city chosen due to its historical relevance as the bridge between the eastern and western Mediterrenean Sea. The reconstruction of the Otranto started with a Digital Terrain Model (DTM) using ESRI ArcGIS and imported in the game engine Torque Game Engine. For the basic models such as the house units, the software Torque Constructor was utilized and resulted in a variety of simple structures that formed the general view of the city. For the more complex models such as the Saint Peter's Church, the Cathedral and the Castle, a CAM was used, achieving a more accurate definition of the structures. These models were later imported into the Torque 3D engine.

FIGURE 4.6: Otranto city with the St. Peter's Church and its surroundings

FIGURE 4.7: Otranto Cathedral

4.4.1 Interaction

The game is divided into two parts, or levels, where the first is an educational level and the latter being an interactive level.

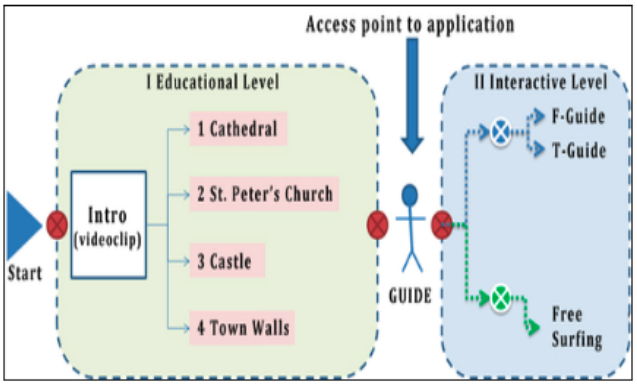


FIGURE 4.8: The interaction and levels in the game.

The game starts with a short introduction video which explains the history of Otranto and then the user can choose to go to one of the four destinations (Cathedral, St. Peter's Church, Castle and Town Walls) or to skip the presentation altogether and start the second level instead. Selecting one of the destinations allows the user to watch a video about the building in the selected destination. The second level starts with meeting the guide (an NPC) which the player can interact with. The player can choose between a guided tour or free surfing where the guided tour has two different options: Facilitator Guide (F-Guide) and Tele-Transportation Guide (T-Guide). Selecting the guided tour with a Facilitator Guide allows the player to follow a specific navigation path through the city, while selecting the Tele-Transportation Guide allows the player to be teleported to the selected point of interest. With the free surfing guide, the player is free to roam the city and explore by themselves. At each interest point, there is a guardian which the player can interact with. The guardian can inform the player about the history and present other types of educational information, such as images and video clips about the point of interest.

To navigate around the map, the player uses a Wiimote (a controller for the Wii game console developed by Nintendo) and a Nintendo balance board. The board has four pressure sensors and can measure what direction the player leans toward. Both devices are connected to the computer through Bluetooth and are using a library for interfacing the Wiimote and other devices called WiimoteLib InputSimulator. The library translates

the input to keyboard/mouse inputs for the computer, and the player moves by leaning in the direction he/she wants to go.

4.5 Summary

There are many educational VR applications available that are relevant for this thesis, but these are a few select ones that have characteristics that are applicable to the application that will be developed for this project. The applications all have different ways for the player to move around in the virtual environment. Two of them use an omni-directoinal treadmill, namely the Virtuix Omni from Climate Quest and the Cyberith Virtualizer from the tunnel evacuation. The MediaEvo Project uses a Nintendo balance board to facilitate the movement, while the Ocean Acidification Experience only allows the player to move with the HMD.

The Climate Quest and Ocean Acidification Experience both feature content regarding climate change, which is the focus for one of the modules in the fire application developed for this thesis. The MediaEvo Project concentrates on cultural heritage which is the other module, and the tunnel evacuation is specifically regarding fire, which both modules include.

Overall, there are many applications that presents these issues separately, however, none has yet to combine them into one. A more detailed comparison of the Fire Quest application and the related work is found in the concluding chapter.

Chapter 5

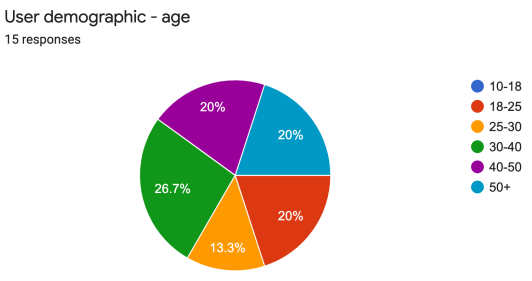
Background testing

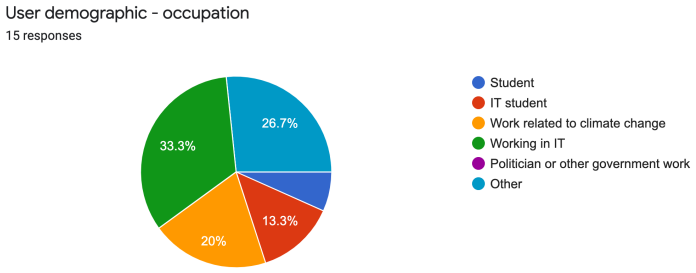
The goal of the semester project was to test the existing Climate Quest application and find improvements that would be implemented in the new application about fire in Trondheim. This chapter contains a condensed version of the results and findings from these tests.

The questions in the surveys were mostly questions using the Likert Scale from ”Strongly Disagree” to ”Strongly agree”. To make an average of the score for each question, the results were mapped into a numerical value. The mapping used was: ”Strongly Disagree” = 1, ”Disagree” = 2, ”Neutral” = 3, ”Agree” = 4, ”Strongly Agree” = 5.

In total, 54 participants tried the Climate Quest application, where 15 of them completed the first survey and the remaining 39 completed the second. The questions are presented below, with a summary of the findings at the end.

5.1 Survey 1





5.1.0.1 Question 3

TABLE 5.1: I felt like I was actually in Trondheim

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	3	7	2	1	2.67

5.1.0.2 Question 4

TABLE 5.2: I felt the effects of the rising sea level stronger in a city I know, such as Trondheim, compared to a generic city

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	0	4	7	0	2.73

5.1.0.3 Question 5-6

TABLE 5.3: I think VR is a good tool to facilitate attitude change regarding climate change

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	5	7	3	3.87

TABLE 5.4: I think VR is a good tool to facilitate attitude change in general

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	3	8	4	4.07

5.1.0.4 Question 7-8

Table 5.5: Seeing the effects of climate change first-hand made a bigger impact on me that it would if I was reading/hearing about it

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	3	7	2	3.40

Table 5.6: This experience motivated me to make changes in my life to act on climate change

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	4	5	3	1	2.73

5.1.1 Usability and realism

5.1.1.1 Question 9-10

Table 5.7: It was easy to understand what to do in the game

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	1	7	7	4.4

Table 5.8: I understood the connection between the sea-level and my actions (removing cars, chimneys, and CO2 molecules) in the game

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	1	2	9	1	3.33

5.1.1.2 Question 11-12

Table 5.9: The graphics of the experience were good

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	6	0	8	1	3.27

Table 5.10: The realism of the experience could be improved to provide a better experience

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	3	4	6	2	3.47

5.1.2 Continued work

5.1.2.1 Question 13

TABLE 5.11: I think it would be interesting to have a similar experience with FIRE in Trondheim (due to climate change) instead of rising sea levels

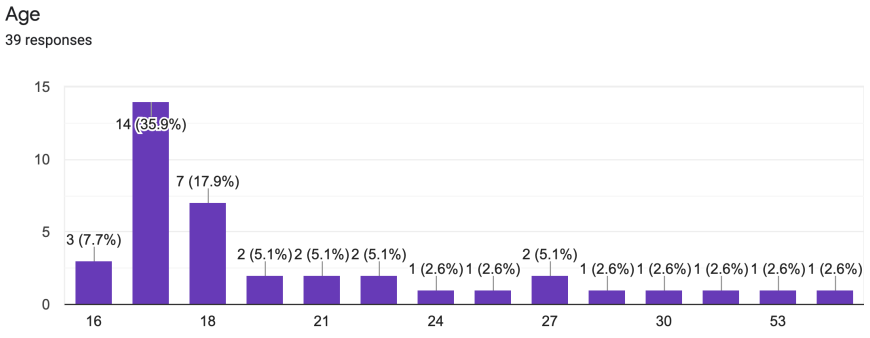
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	1	2	10	2	3.87

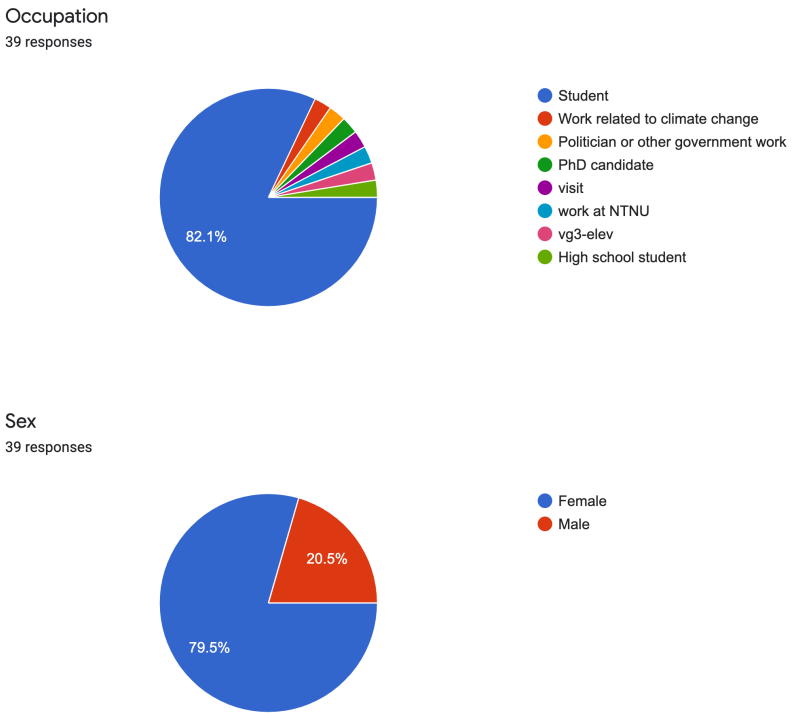
5.2 Survey 2

This survey was designed after receiving feedback from the first survey and includes a separate question for suggestions for improvements. In the occupation section, the categorization is simplified, removing the IT-specific options, and the whole questionnaire is made simpler and shorter. The questions are also more general and include more questions regarding fire and how that could be used in the existing application. It is also specified clearly that the questionnaire is anonymous.

5.2.1 User demographic

5.2.1.1 Question 1-3





5.2.1.2 Question 4

TABLE 5.12: I believe that climate change awareness is important

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	1	2	36	4.90

5.2.2 Climate Quest - Rising Sea Level

5.2.2.1 Question 5-7

TABLE 5.13: I felt immersed in the virtual environment

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	7	15	15	4.10

TABLE 5.14: I feel more immersed when I'm physically running in VR

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	7	12	20	4.33

Table 5.15: Seeing the effects of climate change first-hand in VR made a bigger impact than reading about it

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	10	18	9	3.87

5.2.2.2 Question 8-9

Table 5.16: It is easy to understand what to do in the game

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	0	1	14	23	4.49

Table 5.17: The graphics/realism could be improved

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	6	12	15	6	3.54

5.2.3 Climate Quest - Fire

5.2.3.1 Question 10-12

Table 5.18: It would be interesting/educational to experience Trondheim on fire due to climate change/forest fire

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	2	11	26	4.62

Table 5.19: It would be interesting/educational to experience specific cultural heritages (with more emotional attachment) on fire

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	1	3	12	23	4.46

Table 5.20: It would be interesting/educational to experience safety procedures during a fire in Trondheim

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	1	5	11	22	4.38

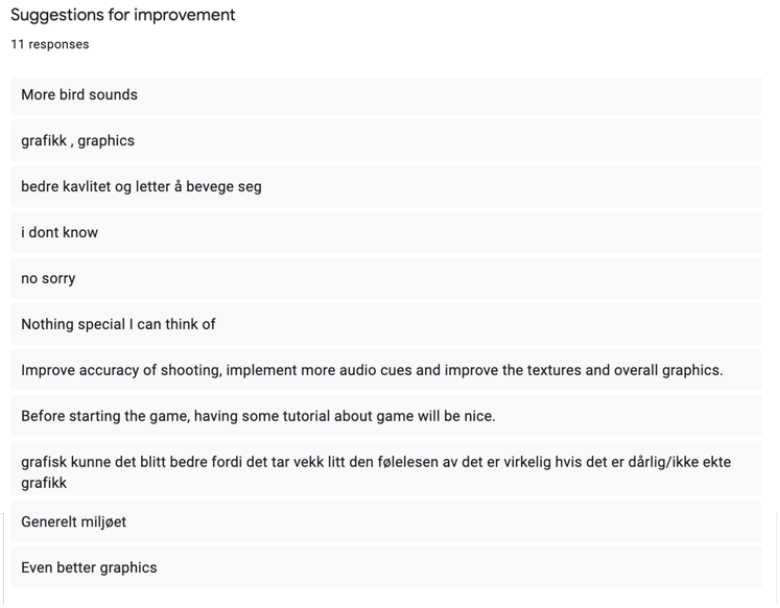


FIGURE 5.1: Suggestions for improvement

The introductory chapter included references to how difficult it is for people to fully grasp the seriousness of climate change due to not seeing the changes first-hand. Looking at the results from the survey, most people agreed that the first-hand experience made a bigger impact than reading about it. However, the experience didn't seem to motivate the participants to make a change to act on climate change. This might be due to the fact that most people who were testing the application were already motivated and knew a lot about climate change. It is to be expected that most people believe that awareness of climate change is important. With an average score of 4.90, it is evident that this is indeed the case. Most people agreed that the game is easy to understand, with an average Likert Score of 4.4. What is also evident, is that people clearly enjoy the Virtuix Omni and feel more immersed when they physically move in VR.

The purpose of the last section of both surveys were to gauge the interest for the upcoming experience about fire in Trondheim. Overall, there is an overwhelmingly positive interest in all three categories for the new application (Climate change, cultural heritage and fire safety). The safety procedures received the lowest score, however, only by a relatively small margin. The last question was an open question to gather feedback on potential improvements. Filtering out the answers that signal "no improvements needed", there are a few categories that emerge: Improved audio cues, improved game mechanics, tutorial, and improved graphics. Below is a table with the categorized suggestions:

Improvement category	Specifics mentioned	People
Improved audio cues	Bird sounds	2
Improved game mechanics	Easier to move, better accuracy shooting targets	2
Tutorial	In the beginning	1
Improved graphics	Environment, textures, doesn't feel real	5

TABLE 5.21: Categorized suggestions for improvement with specifics mentioned

The improved audio cues are most likely related to audio feedback throughout the game. There is already a lot of audio responses to actions in the game (such as shooting targets), but there could be even more. The specific comment regarding "bird sounds" is most likely an indication of a need for more environment sounds to increase realism further. When it comes to the improved game mechanics, the suggestions were to make it easier to move and to make the accuracy of the shooting better. It was noticed during the studies that the targets are sometimes very hard to hit, despite the beam from the gun seemingly going through the target. This causes some frustration for the player. Some people also have a hard time with the Virtuix Omni and do not really get the hang of the movement mechanics. Despite most people thinking the game is easy to understand (Table: 5.7), there is a comment requesting a tutorial for the game. There is already a short text, but the game could present the tutorial in an easier format or through a hands-on tutorial to make it easier to understand how the game works - similar to the Virtuix Omni tutorial every player goes through before trying the experience. Lastly, there is the category of improved graphics. This is by far the most mentioned improvement and includes comments for improving the environment, the general textures, and making it feel more realistic.

5.3 Conclusion

The "Climate Quest" application demonstrates that it is a fully immersive experience which is easy to use and fun to play. Seeing the effects of climate change first-hand makes a bigger impact on most people than it would reading or hearing about it, and this shows potential for future applications to utilize VR to highlight a serious issue. Despite being very immersed in the virtual world, and making direct changes to prevent the sea level rise, the experience did not seem to motivate people directly to act on climate change in

real life. However, since essentially everyone in the studies saw climate change awareness as important, the application still serves its purpose making people more appreciative of climate change and in turn raises the awareness of the issue.

The surveys conveyed a lot of interest in an application with fire spreading due to climate change. Since a lot of people were also interested in seeing cultural heritages in the application, it will be set in Trondheim around perhaps the most iconic cultural heritage in the city - Nidarosdomen Cathedral.

Chapter 6

Requirements and theoretical analysis

This chapter will analyze the game in regard to the game theory described in Chapter 3. The analysis will help determine what aspects of the game can be improved, and together with the results from the conducted studies, it will form the requirements for the prototypes with fire in Trondheim.

6.1 Four fun keys

6.1.1 Easy Fun

The Climate Quest application is a very linear application and does not provide much freedom to explore. This is most likely intentional since most people are only trying it as a demo for a few minutes before the next person can try. However, the full game does include the second module (not tested in the studies conducted in this paper), which includes exploration in Trondheim with a custom quest, including a set of targets and information points. There is not much interaction with the environment either, so the player does not get the feeling of wonder or awe as they run around the map.

6.1.1.1 Suggested improvements

Having a linear application is a good way to ensure that people do not spend a too long time on the treadmill and allows for more people to try the experience. This is a positive aspect that should be preserved; however, it is still possible to make the playable world a bit bigger and with more freedom to run around. The fire could possibly spread from different locations too, making it a different experience for each person testing the application. The fire would interact with the environment, and the player could also interact with it by shooting water at the fire to try and eliminate the spreading fire. The environment itself could also be more interactive, by having grass that moves in the wind, or that the fire moves according to the wind direction and speed. These improvements would all strengthen the Easy Fun of the application.

6.1.2 Serious fun

The aspect of attitude change towards climate change was discussed tested in the studies. Because most people were already motivated towards acting on climate change, the application did not seem to make a huge difference for the majority. (Table: 5.6) However, the experience did make a bigger emotional impact than reading about it, so it has some successful aspects of serious fun regardless. (Table: 5.5, 5.15)

6.1.2.1 Suggested improvements

By implementing realistic fire-spreading in the environment, it is possible that participants could benefit from seeing how fast fire spreads in real life and how difficult it might be to eliminate the fire. It could make them more aware of forest fires or make them open their eyes towards the safety aspects of fire and how to prevent it from happening. The application could also show videos about the topics to educate the participants further.

6.2 Characteristics of fun

6.2.1 Challenge

The Climate Quest experience does a very good job of having a clear goal that is explained well at the beginning of the game and which the progress is evident throughout the game. This is backed up by the studies, which indicated that the majority of the participants found the game easy to understand and understood the references. (Table: 5.7, 5.8) The sea-level rise is visible for the players, and the weather changes as the participants hit more targets. The current sea level and climate are also visible around the player's gun, showing the progress towards the goal. However, it is important to mention that during the studies, it was noted that this information was often not seen nor noticed by the player. There is also no randomness or variable difficulty in the experience at the moment.

6.2.1.1 Suggested improvements

The application can use a similar initial tutorial to make it easy to understand what to do in the game, or even better, a video tutorial could show the players how the game is played. It must have clear goals that are explained well, such as eliminating the fire or performing the required safety procedures after noticing a fire. It could incorporate randomness in how the fire is spreading, how the wind is blowing, or where the initial fire starts. There could also be a variable difficulty, although most participants will try the Virtuix Omni for the first time, which makes it rather inconsequential to implement.

6.2.2 Curiosity

The sensory curiosity is pretty well done in the application. The audio and visual effects of the weather, such as the visible clouds, rain, and sun, as well as the sound of the pouring rain, establish a compelling sensory environment for the player. There is little cognitive curiosity, however, as there is not any information left out for the player to find.

6.2.2.1 Suggested improvements

The sound of the fire as well as a more interactive environment mentioned above will provide satisfying sensory curiosity. There could also be hidden elements around the game which the player could find, such as water buckets hidden behind walls, trees or objects that you could use to eradicate the fire.

6.3 Gameflow

Gameflow	Application	Future work
The Game	- Climate Quest	- Fire Quest
Concentration	- Quickly grabs the player's attention with visible targets - Concentrate on reaching the green light	- Quickly grabs the player's attention with visible fire - Concentrate on taking out the fire
Challenge	- Shoot targets and run towards the green light	- Shoot targets and receive points or water - Use water to eliminate fire
Player skills	- Textual tutorial + Virtuix Omni tutorial for the movement	- Virtuix Omni tutorial for the movement - Video tutorial of the controls and game mechanics
Control	- Running using Virtux Omni - Shooting targets prevents sea level rising	- Running using Virtux Omni in a more free environment - Shooting at the water buckets - Shooting water at the fire
Clear goals	- Reach the green light before drowning from sea level rise	- Eliminate the fire before cultural heritage/forest is burned down
Player skills	- Player progression is infeasible in the short timespan	- Player progression is infeasible in the short timespan
Social Interaction	- No multiplayer	- No multiplayer

Table 6.1: Evaluating the current game using gameflow and suggesting elements for the future work

The Climate Quest application quickly grabs the player's attention with visible targets right after the introductory text explaining what to do. You immediately see cars and chimneys that you can shoot and you concentrate on running as fast as possible towards the green light. With fire in Trondheim, the attention would instantly go towards a visible fire. The player would concentrate on using different game mechanics to take out the fire as quickly as possible. When it comes to the challenge aspect of gameflow, the

Climate Quest has targets around the map that the player can shoot to prevent the sea level rise. The challenge is usually easy enough for people to make it through the game, however, there has been a few cases in the studies that the players drowned. With the upcoming work, there could be water buckets hidden around the area to engage the player to find them. Using the obtained water, the player would take out the fire by shooting water at it like a fire-hose. For the player skills point, there is a textual tutorial at the start of the game that seems to be enough for people to understand what to do. There was one comment in the study that wanted a tutorial, so there might be a tutorial for using the controls in the upcoming application. The controls themselves are performed through running around the environment using the Virtuix Omni and shooting climate targets. The experience could be improved by having a more free environment so the player could explore a little more and not be bound to a linear path. There would be similar controls with one gun shooting at targets and the other shooting water at the fire. Currently, there are clear goals presented in the game which is to reach the green light before drowning. Similarly, there would be a clear goal to eliminate the fire before the cultural heritage or forest burned down. For the player skill element, there is not really any progression in the current application, and there is not really any need for it due to the limited time constraint. People only try the application for a few minutes and do not have time to progress as you would in a more traditional game. The same goes for social interaction as the IMTEL Lab at Dragvoll does not have two Virtuix Omnis, and it is, therefore, impossible to implement multiplayer functionality to the game.

6.4 Requirements

Based on the background study of the Climate Quest application and this theoretical analysis, there are a some requirements for the new application. Table 6.2 shows the requirements with the respective priority.

Requirement	**Priority**
The experience should feature both Climate Change and Cultural Heritage	High
There should be a menu to choose which module the player wants to experience	High
The player should be able to eradicate the fire to win the game	High
There should be fire that propagates with a certain degree of randomness	High
The player should be able to interact with the fire by shooting water at it	High
The fire should be able to propagate in buildings and trees, not just the ground	High
The game should use both VR controllers and the Virtuix Omni treadmill for the interaction	High
There should be a video tutorial explaining the controls and game mechanics	Medium
There should be educational videos explaining the topic of cultural heritage and climate change with examples from real life.	Medium
The player should be able to roam the environment freely, not a linear path	Medium
There should be hidden elements in the map such as water buckets that the player can interact with	Medium
There should be fires spawning from random or different locations	Medium
The environment should be more interactive with moving grass and trees	Low
The fire should be sensitive to the wind direction and speed	Low

Table 6.2: Requirements

Chapter 7

Finished application

7.1 Introduction

The complete application includes two separate modes with similar interactions, but with different goals. The first module focuses on climate change and how the number of forest fires is increasing rapidly with the increase of global temperature. Specifically, the game focuses on the recent devastating fires in Australia and asks the rhetorical question: "*What if the same were to happen in Trondheim?*". The second part is about cultural heritage and presents the case of the recent fires in Notre Dame. The same rhetorical question is raised, and the focus is aimed at the current safety procedures in churches in Norway, specifically Nidarosdomen.

Both modes start in a bright room with some furniture, decoration, and windows. In front of the player are buttons to select which game mode to play, and selecting one of them shows an introductory movie with information regarding the relevant topic selected. It also shows a tutorial of how to play the game before the player is placed in the area around Nidarosdomen, Trondheim. Both games aim is to take out the fire that has started. There are water buckets around the map which the player can pick up with one of the controllers; the other controller is used to shoot water at the fire. The harder one presses the trigger, the faster the water shoots out. The game also has two bars showing in the HUD at all times indicating different elements of the game:

- **Health Points (HP)**: The longer and stronger the fire burns, the more health points you lose. For the first module, the health points are given to the ground, and for the second module, it is for Nidarosdomen. See figure 7.1
- **Water level**: Indicating how much water is left at any point in time. When the player is out of water, he/she must find buckets to refill the supply of water. See figure 7.2

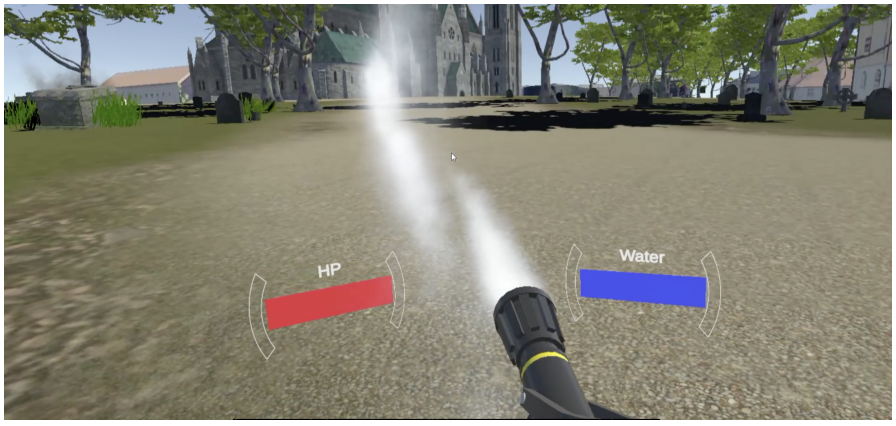


FIGURE 7.1: Using the controller in the right hand, the player can shoot water at the fire. The harder you press the trigger, the faster the water shoots out.

FIGURE 7.2: Water buckets are hidden around the map at random places. The player needs to find these and pick them up to get more water to stop the fire.

7.1.1 Module 1: Climate Change

The climate change module starts off showing a video about the fires in Australia and how climate change is a significant factor in facilitating this. The short movie shows news reporting from the event, interviews from people affected, and a warning that if this could happen in many other places around the world if we do not deal with climate

change. [1] The goal of the movie is to create an emotional response in the participant and to act as a reminder of the dangers of climate change. The player is then shown a tutorial of how to play the game before being placed in Trondheim city near Nidarosdomen and tasked with stopping the fire that's spreading around the area. The fire will eventually die out by itself, but the health points diminish before reaching that point.

FIGURE 7.3: Nidarsdomen on fire

7.1.2 Module 2: Cultural Heritage

The second module regarding cultural heritage preservation shows the player a movie about the fires in Notre Dame and how much of a cultural significance the building has for many people around the world.[2] The rhetorical question of "What if this happened in Trondheim?" is shown and subsequent facts about the current state of safety precautions in churches are presented. The safety procedures in Nidarosdomen are specifically explained while showing drone footage of the cathedral. The player is then shown a tutorial of the game and is taken to Trondheim, where Nidarosdomen is burning. Contrary to the first module, the fire in this module does not stop burning until one specifically takes it out.

[1] Climate change introductory video: https://www.youtube.com/watch?v=4zcerplyE1c
[2] Cultural heritage introductory video: https://www.youtube.com/watch?v=oCWLajGucio

7.2 Technical details

7.3 Specific improvements

Based on the surveys, there were a few specific improvements that could be made to enhance the experience. Among those were improved graphics and realism, and this has been a focus in the Fire Application. The ground has been filled with trees that can burn, and grass that can blow in the wind. The ground turns dark where the fire has burnt, and animated smoke and spark particles erupt from the aftermath. The fire also follows the direction of the wind, although the wind in the game is currently not very powerful. In addition to this, there is a small random aspect to the spreading of the fire, which makes each game a little different.

Regarding the graphics, the initial model of Nidarosdomen is replaced with one consisting of better textures and higher resolution. The ground is converted to a terrain in Unity, which makes adding grass and trees easier and faster and will allow more straightforward control of the fire. Game assets such as graves, fences, and Nidarosdomen itself are added to the scene making it more lively.

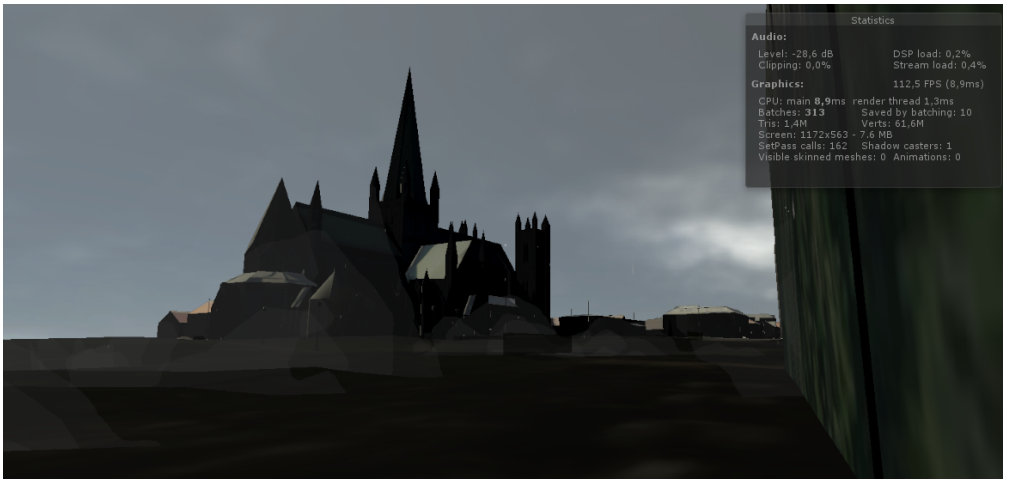


FIGURE 7.4: Nidarosdomen cathedral in the Climate Quest application. Noticeably, it's with the heavy rain module making it look darker

The map is now less linear, where the player can choose to run around more instead of following a specific path. In the first module, the fire spreads on both sides of the path, and the player can choose which side to clear out first. The map is also more open with the whole area around Nidarosdomen to explore (within the fences). Water buckets are hidden around the map and make the player choose different paths to find them.

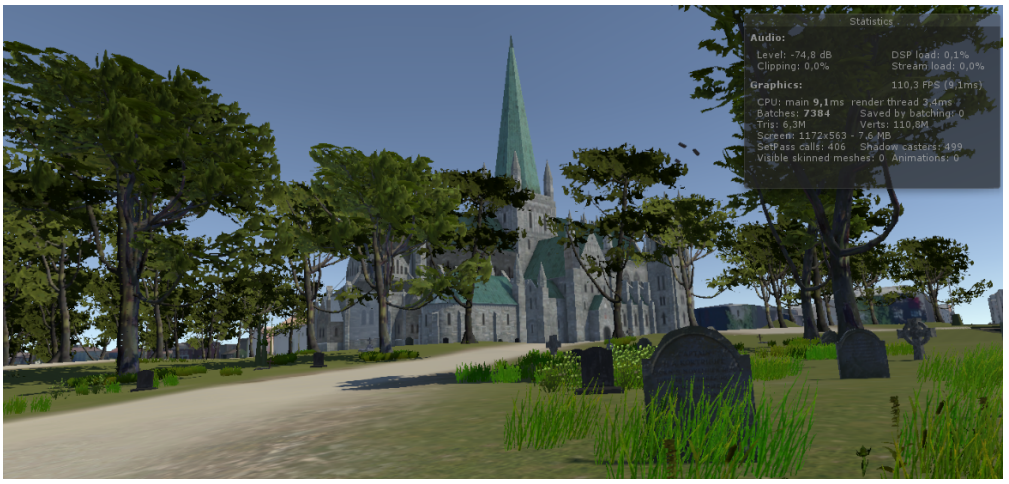


FIGURE 7.5: Improved model of Nidarosdomen cathedral with new terrain textures, trees, grass graves and more

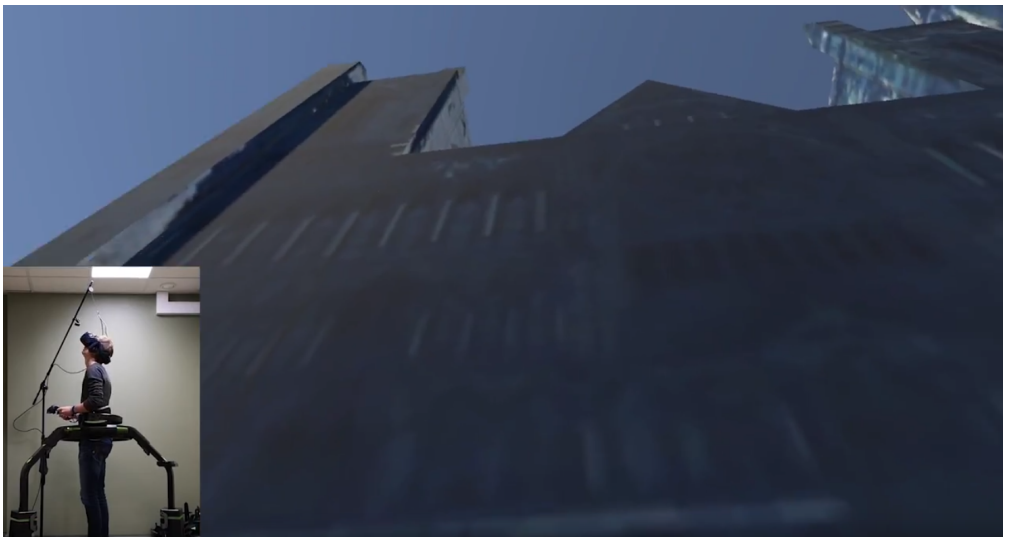


FIGURE 7.6: The old Nidaros model from the Quest application without rain

7.4 Videos

There are two videos present in the game, both shown in the starting room of the experience. These videos serve two purposes:

- To demonstrate facts about the related topic (Climate Change or Cultural Heritage) and to increase the player's awareness of the issues.
- To present the game mechanics and how to play the game.

The first part is done by displaying news about current events of Climate Change and Cultural Heritage. The news covers the fires in Australia and the fires in Notre Dame

FIGURE 7.7: Improved Nidarosdomen model

respectively, and serves as a reminder of the seriousness of the issues. There are also posters along the wall on how you, as an individual, can make an impact on climate change. For the part about Nidarosdomen, I have used personal drone shots.

7.4.1 Tutorial

A better tutorial for the game was requested from the survey and from the theoretical analysis of the Four Fun Keys, so this has been one of the focus points for the fire application. The tutorial is now in video format and explains the purpose of the game while showing gameplay. It also shows how to use the controls and lets the player test it out while watching the video. To make the voice-over clear, concise, and easily understandable, I ordered a recording from a certified voice actor on Fiverr.

7.5 Fire propagation

Parts of the fire propagation system in the game is from the Unity asset store and has been modified to accommodate the needs of this project. [3] To make the fire propagate over both the ground and objects in the scene, it has been implemented two different ways a fire can spread in the game:

[3] https://assetstore.unity.com/packages/tools/fire-propagation-92187

- **Grid**: A specified grid (with given size) is created with each cell representing a small fire. Each cell has values for how much ”fuel” and how much ”HP” it has based on which terrain texture it uses.
- **Chains**: A specified chain of nodes is created with each node representing a larger fire. Each node needs to specify which other nodes it can propagate into, and they each have their own ”fuel” and ”HP” values.

The ground around Nidarosdomen is made up of Unity Terrain. This makes it easy to paint terrain textures (such as grass, pavement, gravel paths) on the ground and makes it easy to manipulate the height and shape of the ground. It is also a great tool to add trees and grass to the area. The area consists of several different terrain textures, and each of the textures has an HP and fuel value. For example, the grass starts to burn easier and also burns for a relatively short time before the grass is gone, so it has a lower HP (the time it takes to ignite) and a lower fuel value (the time it takes to burn up). Conversely, the gravel will have higher HP and a lower fuel value since it takes a long time for the area around a gravel path to start burning, and it does not burn for long.

After the fire starts, each subsequent cell is first heated up to ignition temperature before starting its fire in the cell. The HP value of the cell decides the ignition temperature; the higher the HP value, the longer it takes to reach ignition temperature. After the cell is on fire, the fuel starts to burn out; the more fuel a cell has, the longer a fire will burn in that specific cell. Once the fuel is used up, the fire stops. That means that when the player shoots water at the fire, the fuel values of each cell decreases, ultimately making it die out.

This fire propagation method works great for the ground where simple textures are enough to differentiate the different ground types. However, it is not enough for complex objects that have different shapes, sizes, and textures. Perhaps a part of an object should burn faster than another, or certain parts should not burn at all. For this, we need manual control over exactly how the fire should propagate. To facilitate this, chains of fire nodes have been created for each object.

Each node in a chain is linked to other nodes in the chain - nodes it is allowed to propagate to. Every node also has the possibility to have different fuel and HP values. For example, The trees have higher values for the trunk of the tree, while the top part

FIGURE 7.8: The trees are made up of a chain of nodes (cube meshes). Each node has specified the links to the next nodes that should burn. The HP and fuel values for the trunk of the tree is higher than the leaves and branches. The mesh renderer for each node is hidden, so the player does not see them in-game.

of the tree with leaves and smaller branches has lower values, so it burns quicker. This means, however, that for larger objects such as Nidarosdomen, it requires much manual work to place all nodes and link them together. Each node in Nidarosdomen has four nodes; it is attached to, and there are hundreds of nodes that make up the cathedral in the game.

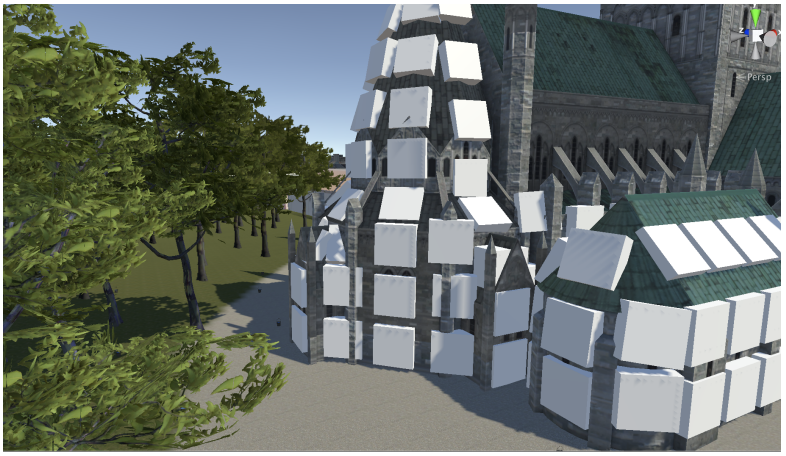


FIGURE 7.9: Hundreds of chain-nodes covering the east side of the cathedral

Chapter 8

Studies

8.1 Method

Except for the last survey and interview, all the studies are conducted in the same way as for the semester project. The IMTEL VR lab at Dragvoll often has visitors from all over the world, and this is the perfect opportunity to test the application on a diverse set of people. Participants' occupations include scientists, politicians, teachers, students, and more, and they all have different backgrounds and knowledge about VR, climate change, and fire. The participants tried the virtual application (either the Climate Quest app or the Fire app) and answered a short questionnaire immediately following the experience. There were two surveys regarding the Climate Quest app, where the latter being an improved version of the first one based on feedback from my supervisor. There were also two surveys regarding the fire application, one regarding the climate change module and another about cultural heritage preservation. A total of 15 people answered the first survey in the background testing with the Climate Quest app, while 39 people answered the second. A total of 16 people tested the fire application, and 33 people answered the online survey after watching me play the game. Lastly, one VR expert tested both fire applications through remote testing. Thus, more than 100 people participated in this project, and the results and discussion of each of these studies will be given in the next chapter. No compensation was given to any of the participants.

8.2 Materials

The immersive VR experience was created with the game engine Unity and rendered with an Alienware PC with Intel Core i9-7900X CPU @ 3.3GHz with 32Gb RAM using Windows 10. Participants were using the HTC Vive Pro head-mounted display for the visual aspects of the game. It uses a high resolution dual AMOLED 3,5" display with 2880x1600 resolution (1440x1600px per eye) at 615PPI. The refresh rate of the HTC Vive is 90Hz (e.g., 90 frames per second, per eye), and it has a 110 degrees field of view. The headset also includes an audio headset that wraps around your ears, providing active noise cancellation as well as a microphone. To interact with the world, the participants used two Vive Controllers, which includes 24 infrared sensors that detect the base stations to determine the location of the controller using the SteamVR Tracking System. These updates from the controllers range from 250Hz to 1kHz. Lastly, there are two Vive Base Stations that create a 360-degree virtual space and emit 60 infrared pulses each second that is picked up by the headset and controllers.

Participants were moving around in the virtual environment with 360-degree freedom of movement using the Virtuix Omni. The Virtuix Omni has a footprint of 55" (140cm) wide and 55" (140cm) long with adjustable height from 35" (89cm) to 44" (112cm). It is designed to accommodate a user height ranging from 142cm to 195cm and a weight up to 130kg. The participants were wearing Omni Overshoes - allowing them to wear their shoes underneath - in either of three sizes: small, medium, or large. Attached to the shoes were Omni Tracking pods to accurately track the movement of the user's feet as they move around in the virtual space. The user would also be strapped in an Omni harness in either small, medium, or large size, (small: Waist Size 61cm - 74cm, medium: Waist Size 75cm - 94cm, large: Waist Size 95cm - 112cm). To manage the HMD cables during playtime, a VR Boom was used. The base of the Omni was cleaned with "EASY-WALK" base polish as often as possible to maintain the low-friction surface of the Omni. [40]

8.3 Procedure

The participants were seated on a chair to make it easier to put on the shoes required to operate the omnidirectional treadmill. While putting them on, I would small talk

about the application, the procedure, or explain how the Virtuix Omni works. The participants would be warned the surface is slippery and then move on into the machine to be strapped in with the harness around their waist. I would make sure the height was adjusted to each person as well as the shoe size being fitting. Then I would show them the HTC Vive headset and explain to them how they can adjust the headset to fit their head and to make sure their view wasn't blurry. Any participant with glasses would have them removed before putting on the HMD unless they absolutely needed to have the glasses on. In these cases, we would carefully leave them on inside the HMD.

FIGURE 8.1: A participant using the Virtuix Omni.

To make the participants familiar with VR and how to navigate the virtual world using the Virtuix Omni, they would first be presented with a tutorial of how to use the treadmill. This step-by-step interactive guide familiarizes the participants with walking and running in VR. After this instructional experience, they would be presented with the Climate Quest Application or the Fire application. When first starting the Climate Quest, there is a short written text on how the game works, but I would often explain this verbally to make sure they understood the concept and to make them more comfortable.

They would then attempt to run towards the green light shooting cars, chimneys, and CO2 molecules along the way. If they were running in the wrong direction, I would assist them verbally to make sure they managed to find the right way across the bridge. In the end, I would explain that they would have to *physically* press the finish button to get the results. The participant would then see the final result with the time spent, the number of targets hit as well as the current sea level. For the fire application, I would let them explore the room and have them press the button to start the experience. An introductory video would play, either regarding climate change or cultural heritage, following a video tutorial of how to play the game. The player would then run towards the fire and start shooting water at it. After depleting the water supply, the player finds water buckets around the map to refill it. After either taking out the fire, or losing all the health-points, the player is transported back to the room where the player can see the result. Following this, they would exit the machine, take off their shoes, and I would kindly ask them if they could answer a short survey based on the experience they just had.

8.3.1 Microsoft Forms

The last survey was done through Microsoft Forms because of the COVID-19 outbreak and the subsequent shutdown of schools and universities in Norway. The participants of the survey were given instructions in the medium where the link was posted (Facebook, Slack, mail..etc.) as well as in the survey itself. A video of the gameplay was linked, where three parts were shown:

- Introductory video
- Tutorial
- Gameplay

Each part is explained in further detail with text on top of the video and the form was sent out to friends, family and colleges through Facebook, Slack, email and other messaging platforms for maximum reach.

8.3.2 Interview

The interview and final testing had to be conducted remotely with the participant in the lab as the VR expert. The procedure was similar to that of the normal testing, since I was remotely controlling the computer with TeamViewer, and the participant could hear me through the headset the entire time. He was already familiar with the Virtuix Omni and the equipment, so no explanation was needed on that part. Following the testing, there was an interview about the experience to get his feedback as a VR expert. The interview was conducted through the video-conferencing application Zoom, recorded and later transcribed. (see Appendix)

Chapter 9

Results - Fire Quest

9.1 Introduction

It was conducted several experiments with different groups visiting the lab during the year, with participants answering one of the surveys. The questions in the surveys were mostly questions using the Likert Scale from ”Strongly Disagree” to ”Strongly agree”. To make an average of the score for each question, the results are mapped into a numerical value. The mapping used in this thesis are: ”Strongly Disagree” = 1, ”Disagree” = 2, ”Neutral” = 3, ”Agree” = 4, ”Strongly Agree” = 5.

Each of the statements and its results will be presented with a rationale for why the question was included in the survey. Similar questions are grouped into logical groups that were also present in the survey. The first survey included ”User demographic”, ”Difficulty of the game”, ”Tutorial and introductory video”, ”Educational vs. entertainment value”, ”Suggestions for improvements”, and ”User experience Questionnaire. Lastly, the categories for the second survey were ”User demographic”, ”Entertainment value”, ”Educational value”, ”Realism”, and ”Suggestions and other comments”. The sections of this chapter will, therefore, also follow a similar structure.

After starting the development of the new application with fire in Trondheim, an initial user test was conducted before the first prototype was finished. This lead to the findings of bugs and improvements which were implemented in the first prototype that was used for the first survey. The second survey used the subsequent prototype with a new module for cultural heritage preservation.

Positive feedback		**Negative feedback**	
Statement	**# of people**	**Statement**	**# of people**
Would recommend	2	More/easier to find water buckets	4
Good game	4	More sensitive running	3
Interesting/different	1	Hit box on bucket	1
Fun to play	3	Fire in Nidarosdomen	2
		Missing tutorial	1
		Move through finished flames	3

9.2 User testing

9.2.1 Middle School Students: 28.01.20

While working with the project on the 28th of January, the lab had visitors from a school class of 13-year olds. I did not have a full prototype ready, nor did I have a questionnaire or interview template prepared; however, the students still wanted to test my application. The solution to this situation was that I let them test the application while taking notes of the casual conversations we had during the testing. A total of 8 people tested the unfinished prototype, and below follows a summary of the notes. The full document is in the appendix A.3.1.

The table shows the recorded positive and negative statements and the number of people who said it. The participants were asked to comment on the improvements that could be made, yet a lot of them chose to give positive feedback regardless. However, this section will focus on the improvements only. The first improvement is regarding the water buckets in the game. At that time, there were only a few water buckets around the map, and some of them were pretty hidden. This made the players run around looking for water buckets, and some of them would not be able to stop the fire in time. The second point is about the running aspect of the game. I noticed later that day that The Virtuix Omni was configured with lower sensitivity than usual, and this caused some frustration from the participants because they would run without getting the proper feedback. In addition to this, there were a few obvious bugs that were detected during testing. One of them was that the hitbox on the water-buckets was set to the water inside the bucket and not the bucket. This meant that the players would have to aim at the water to pick up the buckets, which is unintuitive. Another bug was that the fires had a hitbox on them (to register when water particles hit), but this would make the player unable to move through them. This is fine when there is an actual fire because you do not want

the player to move through the fire; however, it was also present even after the fire was taken out, and the smoke animation was playing. This was not intentional since the player should be able to run through the smoke. There were also mentions of wanting a fire in Nidarosdomen, or some of the buildings nearby. Lastly, there was a person mentioning the lack of a tutorial.

9.2.1.1 Improvements

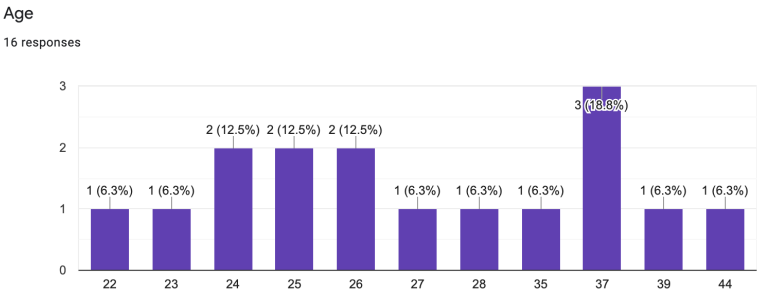
Despite not being fully prepared for testing, I still received some valuable insight that will be improved for the prototype. The prototype will now have more water buckets available, which are easier to find and with the correct hitbox so that they are easy to pick up, and the Virtuix Omni settings will be configured better to give the participants a more pleasant running experience. For the last module, where the focus is on cultural heritage, there will be a fire in Nidarosdomen instead of the area around it, and there will also be a tutorial for both modules. Lastly, the bug with the flames will, of course, be addressed and fixed.

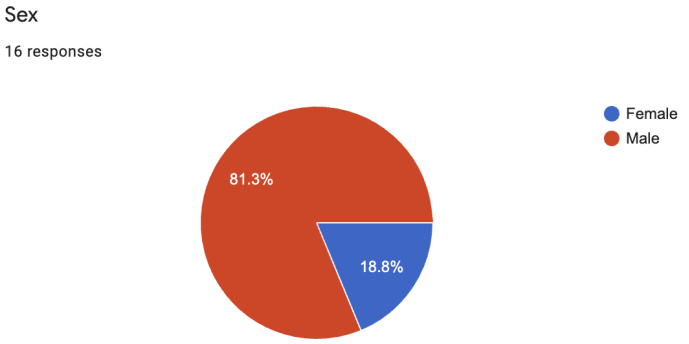
9.3 Survey 1

This survey was designed to test the first finished prototype of the Fire Application. The prototype is with the module regarding climate change and includes an introductory video with instructions on how to play and information about the devastating fires in Australia. The goal of the survey is to see if the tutorial is working, how well the difficulty of the game is adjusted, and what educational and entertainment value the participants gain from the experience. There is also a section for general suggestions for improvements or other comments. Lastly, there is a User Experience Questionnaire (based on the UEQ papers in the theory section) to see how good the UX is and compare it to a benchmark of other applications using the same survey.

9.3.1 User demographic

9.3.1.1 Question 1-2



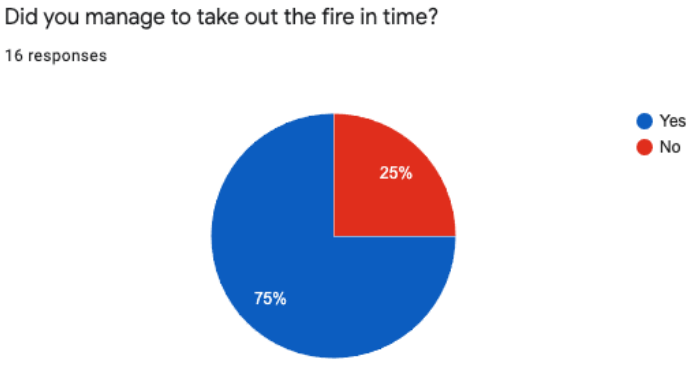


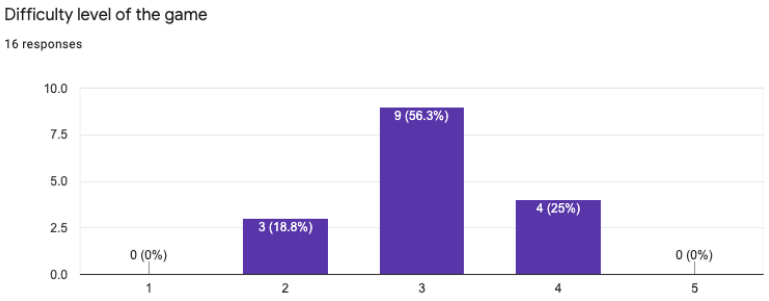
Rationale

People respond differently to any user testing, and often this can be due to the user demographic. Younger people tend to understand technology faster than older people for example, and different cultural generations might affect the result. Gender also plays a role, especially for VR games where there is a significant difference in interest between men and women. [41]

9.3.2 Difficulty of the game

9.3.2.1 Question 3-4





Rationale

There is a fine balance between a game that's too easy and too hard to play. If the game is not challenging enough, it comes off as boring and mundane to the user. If it is too complicated, the player gets frustrated and leaves with a negative experience of the game. Since there will be a lot of different types of players that will play this game - people in different age groups, with varied experience and diverse background - it is important to find a solid middle ground that leaves most people satisfied with the experience. Taking out the fire means winning the game, so this is an indicator of whether the player managed to complete the tasks to accomplish this.

9.3.3 Tutorial and introductory video

9.3.3.1 Question 5-6

TABLE 9.1: I understood how to play the game after seeing the tutorial

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	1	2	13	4.75

TABLE 9.2: I think the opening scenes (with fires in Australia) were a good reminder of the dangers of climate change

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	1	5	10	4.56

Rationale

From the previous surveys, there were suggestions for making a better tutorial for the game to make it easier to start playing without the need for instructions. The game mechanics are a little more complicated compared to the Climate Quest app since the

player has to use two hands with different functionality (one hand for shooting buckets and the other for taking out the fire) and with a more open space to navigate around instead of following a set path. There is also the concept of health points and water remaining that adds to the complexity. Because of this, there was most likely a need for a tutorial for the game. In addition to this, there is a part about climate change where a comparison is made to the recent devastating fires in Australia. The purpose of this is to serve as a reminder of climate change. These questions address whether the tutorial was effective in teaching the game and whether the opening scenes had a positive effect as a reminder of climate change.

9.3.4 Educational vs entertainment value

9.3.4.1 Question 7-9

Table 9.3: I had fun playing the game

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	0	4	10	4.38

Table 9.4: I know a lot about climate change

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	2	9	5	4.19

Table 9.5: I learnt something new about climate change after the VR experience

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
5	4	4	1	2	2.44

Rationale

Educational games can be fun while providing academic value. A portion of the theory in Chapter 2 is dedicated to this, with GameFlow, the Four Fun Keys, and the three essential heuristics for making a game fun. An analysis of the Climate Quest in regard to these studies, as well as suggested improvements, can be found in Chapter 4. The first question is to see if the participants had fun playing the game, while the two others are to see if they learned something new about climate change. To serve as a baseline, the people are asked if they know a lot about climate change already. If they do, they are less likely to learn something new.

9.3.5 Suggestions for improvement or other comments

9.3.5.1 Question 9-10

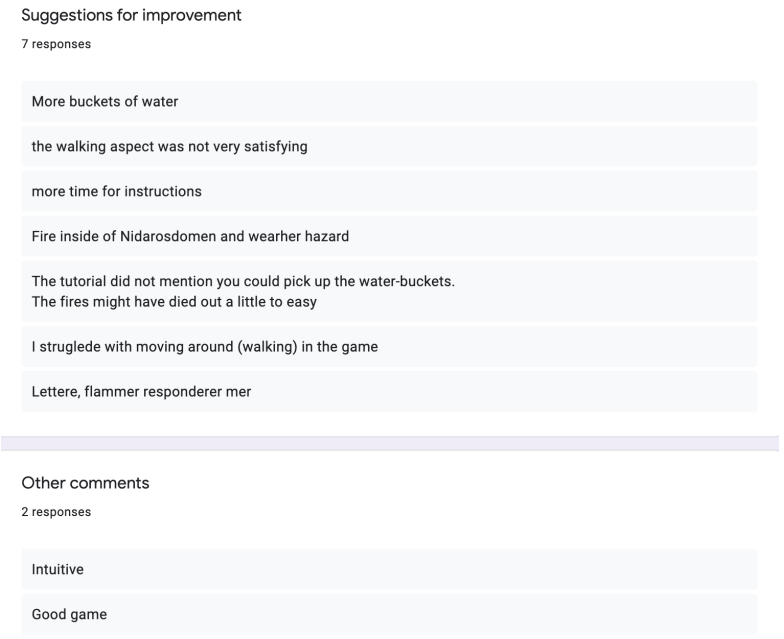


FIGURE 9.1: Suggestions for improvement

Rationale

There is always room for improvement, and the questions in these surveys might not convey what the participant is feeling or missing from the experience. Therefore, there is a free-text question in the survey in which the players can suggest their own improvements to the game. There is also an option for any other comments to be made.

9.3.6 User Experience Questionnaire (UEQ)

9.3.6.1 Question 11-19

TABLE 9.6: Obstructive - Supportive

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	0	2	5	8	4.4

TABLE 9.7: Complicated - Easy

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	1	3	7	4	3.93

Table 9.8: Inefficient - Efficient

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	1	6	3	5	3.80

Table 9.9: Confusing - Clear

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	1	2	6	6	4.13

Table 9.10: Boring - Exciting

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	3	1	4	7	4.00

Table 9.11: Not interesting - Interesting

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	2	1	4	8	4.20

Table 9.12: Conventional - Inventive

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
0	2	2	2	9	4.20

Table 9.13: Usual - Leading edge

Score: 1	Score: 2	Score: 3	Score: 4	Score: 5	Average
2	0	2	9	2	3.40

Rationale

The reasoning and theory behind the UEQ is explained in detail in the relevant section of Chapter 2.

Item	Mean	Variance	Std. Dev.	No.	Negative	Positive	Scale	
1	2,2	1,1	1,0	15	obstructive	supportive	Pragmatic Quality	
2	1,5	1,5	1,2	15	complicated	easy	Pragmatic Quality	
3	1,3	2,0	1,4	15	inefficient	efficient	Pragmatic Quality	
4	1,8	1,6	1,3	15	confusing	clear	Pragmatic Quality	
5	1,6	2,8	1,7	15	boring	exciting	Hedonic Quality	
6	1,9	2,3	1,5	15	not interesting	interesting	Hedonic Quality	
7	1,9	2,6	1,6	15	conventional	inventive	Hedonic Quality	
8	1,0	2,7	1,7	15	usual	leading edge	Hedonic Quality	

Figure 9.2: A table showing the results of the UEQ in terms of the mean, variance and the standard deviation. There is also a division between the two qualities.

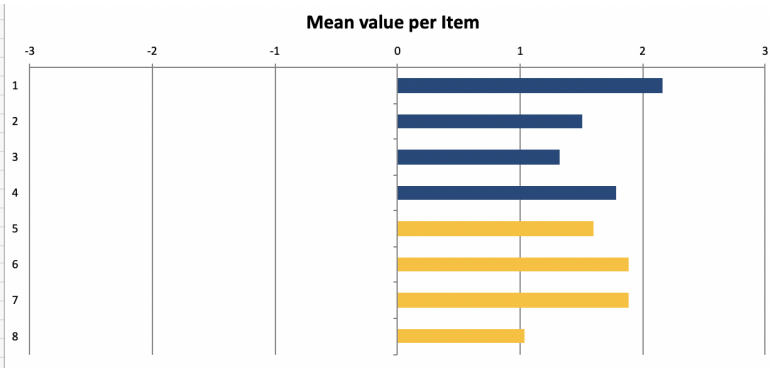


FIGURE 9.3: A graph showing the mean value for each of the questions in table. All values are above 1 which is considered a positive evaluation. 9.2

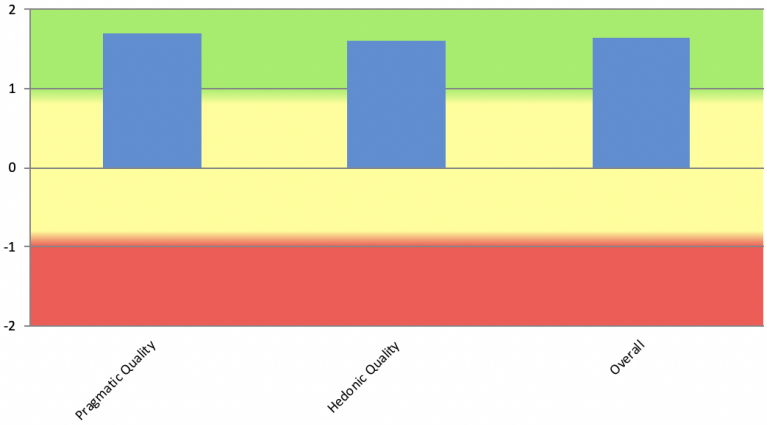


FIGURE 9.4: A graph showing the mean from the two categories respectively, as well as an overall mean. The values below -0.8 (negative evaluation) are indicated in red while the values above 0.8 are indicated in green. (positive evaluation) The neutral evaluation between -0.8 and 0.8 is indicated in yellow

9.4 Survey 2

This survey was designed to test the second finished prototype of the Fire Application and includes a new introductory video regarding cultural heritage and a new tutorial. However, due to the COVID-19 outbreak across the globe, the testing was not conducted physically in the lab. The testing was done by sending out a survey online with an attached video of the gameplay and recording the feedback from this.

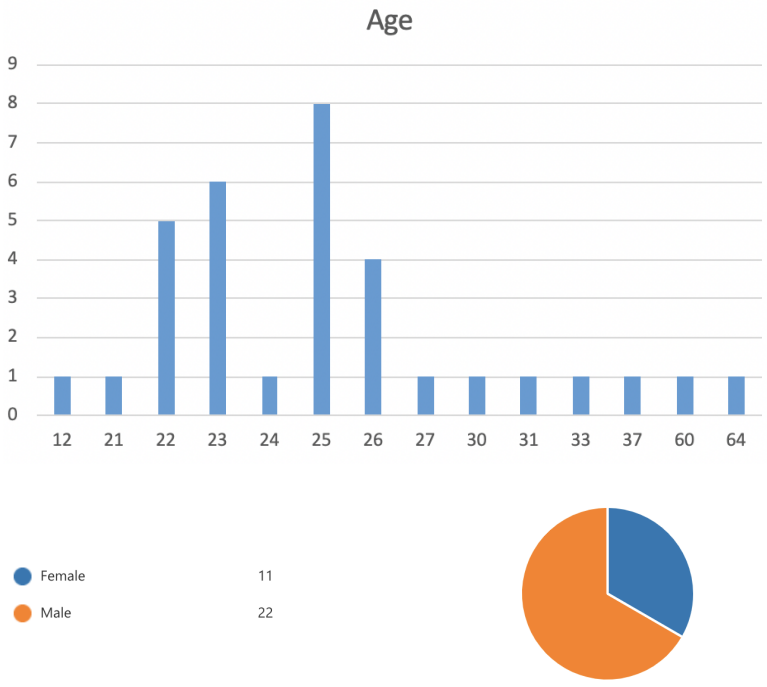
9.4.1 COVID-19 Outbreak

COVID-19 is an acute respiratory disease that was first identified in December 2019 in China. In the coming months, the spread of the virus gained traction, and the first

confirmed case in Norway was in Tromsø the 26th of February. To combat the rapid escalation of the disease, the Norwegian government issued the strongest and most radical measures ever seen in the country since war times. This included closing kindergartners, schools and universities, introducing border control and travel restrictions, canceling major events, promoting self-quarantine in the homes, and much more. This had major impacts on the society, and the lab and the rest of NTNU were closed for an indefinite period of time. As of such, it became impossible to test the VR application with the Virtuix Omni in the lab, and the master students had to come up with alternative solutions to the testing aspect of the master theses. One such solution was to create a video of the gameplay with overlaying text or voice that explains the game and send this with an accompanying survey. This is the solution that has been implemented here. [1] The survey is done through Microsoft Forms instead of Google Forms due to better privacy and NTNU having a contract with Microsoft for the Office Suite.

9.4.2 User demographic

9.4.2.1 Question 1-2



[1] Video: https://www.youtube.com/watch?v=y_C-7j01lRo&t=

Rationale

Same rationale as the previous user demographic section above.

9.4.3 Entertainment value

9.4.3.1 Question 3-4

TABLE 9.14: I want to try the game

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	3	7	15	8	3.73

TABLE 9.15: The game seems fun to play

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	4	8	16	5	3.67

Rationale

The four fun keys according to Nicole Lazzaro are what makes games fun and engaging. (Isbister et al., 2008) [21] The theoretical analysis of the Climate Quest in chapter 4 revealed possible improvements that were implemented in the fire application to make the game more fun. For the participants, wanting to try the game indicates that it seems worth the time to try it and that it seems like a fun experience. The second question directly asks if the game seems fun to play. Since the participants cannot test the game themselves, the questions simply indicate the desire to play and if the game seems like an enjoyable experience. The game should be both fun and educational, so the next section is about the educational value of the application.

9.4.4 Educational value

9.4.4.1 Question 1-2

TABLE 9.16: I know a lot about cultural heritage preservation in general

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
6	14	10	3	0	2.30

TABLE 9.17: I learnt something new about cultural heritage preservation in Norway

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	9	14	8	3.85

TABLE 9.18: I believe we need to do more to protect the churches in Norway

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	1	10	14	8	3.88

TABLE 9.19: I learnt something new about the fire safety in Nidarosdomen

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	0	2	15	15	4.30

Rationale

Ultimately, the goal of the game is for the users to raise awareness about the two topics: climate change and cultural heritage preservation. To do this, it is important that the experience provides some educational value and teaches or at least reiterates some knowledge about the topics. The main method for this is through the introductory movies, but also by letting the users experience the consequences first hand where Nidarosdomen is on fire. The first question in this section is used as a baseline to see whether people already know a lot about cultural heritage preservation. If a lot of people disagree with this statement, then there is a potential for learning something new about the topic. The second and fourth question address this and ask the participant if any new knowledge about the respective topic was acquired after the experience. Lastly, the question in table 9.18 tests if the experience made an impact on the participant - enough to believe we need to do more to protect the churches in Norway. Especially interesting is to see whether the users who does not know much about cultural heritage preservation from before are more inclined to think we need better protection of Norway's churches after the experience.

9.4.5 Realism

9.4.5.1 Question 4-6

TABLE 9.20: The graphics are good

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
2	5	9	12	5	3.39

TABLE 9.21: I believe running on a VR treadmill makes the experience more realistic

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	3	1	10	19	4.36

TABLE 9.22: I believe I would remember the experience better if I was physically running in VR than only using controllers

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	2	0	14	17	4.39

Rationale

Feedback from previous surveys on the Climate Quest application stated that the graphics and realism could be improved. This has therefore been a focus when developing prototypes for a fire application. Several improvements (mentioned in Chapter 7) were made to make the game more realistic, and the first question in table 9.20 is considering these improvements. The last two questions are about the importance of the Virtuix Omni and how running in VR might make the experience more realistic. Because the game is educational, it is important that the user remembers the experience and the knowledge gained from it. The question in table 9.22 compares the recollection from using the omnidirectional treadmill and using regular controllers.

9.4.6 Tutorial/opening scenes

9.4.6.1 Question 1-2

TABLE 9.23: I understood how to play the game after seeing the tutorial

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
0	0	0	5	28	4.85

TABLE 9.24: The opening scenes (with fires in Notre Dame) reminded me of the importance of cultural heritage preservation

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average Score
1	0	1	15	16	4.36

Rationale

The tutorial was very effective in the last module, so the tutorial for this part regarding cultural heritage was relatively similar. The opening scenes, however, although following the same theme, were very different from the last module. Therefore it was important to see if the changes in the tutorial and opening scenes still resulted in positive scores. Raising awareness of cultural heritage preservation is the goal of the videos, and the question in table 9.24 addresses this concern.

9.4.7 Suggestions and other comments

9.4.7.1 Question 1-2

FIGURE 9.5: Average rating

Rationale

In the Microsoft forms, there is an option to select a question with a star-rating. This is not possible in Google Forms, so there was a good opportunity to use it to end the survey with an overall rating of the game. The user can choose from 1-5 stars, similar to the other questions with a Likert scale, but with the added feeling of being a reviewer for the game. The suggestions and comment section are simple text fields where the user can input anything they want as the last method to give their remarks about the game. The answers are summed up in the categorized table 10.2 with the categorizations, specifics, and the number of people who mentioned a comment in the category.

FIGURE 9.6: Suggestions for improvement

Muligens at bøttene med vann er større, men at du må være innen en viss radius fra dem før du kan plukke dem opp	Better looking fires, more objectives than to only put out fire
Pilking up buckets from a distanse is a bit weird	Grafikk
The game seems okay for educational purposes, for example if the game was possible to play as part of a tour through Nidarosdomen. However, I would not spend money to play this game for pleasure at home. Maybe it there was a compelling storyline, with several levels and with differering gameplay between each level.	I like the idea! But considering how much equipment is needed to play, the game feels a little too simple
I didn't really see the connection between running around picking up buckets of water with all the issues described in the pre-game movie, eg. sprinkler systems and direct connection to the fire department	Would be cool with a fire truck!
Run a bigger distance will make the game more stressful and maybe increase the point you are trying to make that our cultural heritage is not very protected	I think the game looks great, I wish i could try it. Think I would have learned a lot from it.
Lyden av vannstrålen blir nok oppfattet som skjærende i lengden. Mulig å gjøre lyden «fyldigere»? Hvis man skal åpne for mer spill-vinkling så ville det vært fint å ha et lite kart i et av hjørnene på skjermen som viser hvor brannen befinner seg i bygget. Da er det lettere å vite hvor man eventuelt skal løpe. Er det forresten nødvendig å starte det lille stykket unna bygget som gjør at man må løpe før «spillet starter»?	Give greater feedback on where you're actually hitting the flames. Could be some smoke-effect or other types of particles.
	Additionnal features, other tools to deal with the fire
	Mer forflytning rundt Nidarosdomen, behov for kontroll av at brannen er skikkelig slukket, kanskje noe lenger tidsperspektiv.
	Obstacles when parts of the church collapses so that it becomes harder to finish the longer time you use.
	Make the refilling of water a bit more immersive? Maybe include a pump or something to keep it closer to reality?

FIGURE 9.7: Other comments

Good job	Stilig å koble 3D tredemølle med spill
Not really sure if being a lone firefighter with super powers in a world where buckets of water seems to be more common in nature than trees will really help me take action to make sure historical buildings are protected from fire. Also, what exactly should I do to prevent these fires, except from grabbing a bucket and running towards the flames?	Could you add more smoke and crackling sound to make it even more dramatic? Maybe other people shoutong around you. I really like the stressfullness tjat you have to run to goet your water and hurry to put down the fire!
Keep up the good work	
Selv om dette ikke gir de samme tilbakemeldingene som om jeg hadde testet det live så tror jeg denne formen for tidlig testing (video, spørreundersøkelse) er ganske effektiv. Kul løsning på utfordringen!	
I really like this idea and this initative!	
Du er flink Morten <3	
Good luck with the project.	
Good luck with the game :)	
Good work! Really impressive	

9.5 Interview with VR expert

Due to the COVID-19 outbreak, the interview with a VR expert had to be done remotely since there was only one person with access to the IMTEL VR Lab at Dragvoll. He is

a researcher at the Department of Education and Lifelong Learning with the IMTEL group and VR/AR lab (IMTELlab) and is specializing in Mixed Reality (VR/AR/MR) for learning, Serious Games, user studies and Human-Computer Interaction (HCI). In this section, he will be referred to as the ”VR expert, ”informant” or ”participant”. During the test, I controlled the computer via TeamViewer and talked to him through the speakers in the VR headset. He tested both the Cultural Heritage and Climate Quest module, and after the test, we sat down on the video-conferencing app Zoom to discuss the experience. The interview was recorded and later transcribed, and the results from the interview are evaluated using thematic analysis.

The first part of the thematic analysis was to familiarize with the data. This included listening to the recordings of the interview and transcribing it. (The whole transcription is included in the Appendix) After the transcription, I re-read the transcript and fixed a few mistakes. The second step was coding of the text, which meant highlighting text, usually phrases or sentences, that could be categorized in defined labels. The table below are the coding used with the corresponding colors used to highlight the text. (This highlighting is evident in the Appendix)

Coding	**Details**	**Color**
Bugs/problems/improvements	Any problems with using the application and potential improvements mentioned	Red
Immersion	Immersiveness and the sense of prescense in the game	Green
Surroundings/hardware	Problems related to the surroundings or hardware	Blue
Graphics/realism	The graphics and realism of the game	Magenta
Informative, shocking	Enlightening and informative information conveyed to user user, sometimes even shocking information.	Cyan
Emotional effect/ Motivational effect	What kind of emotional effect the game had on the player	Purple
Metaphors	Potential metaphors evident in the application	Yellow
Running	How the running in VR using the Virtuix Omni was	Brown

Table 9.25: Coding from the interview with details and the corresponding color used for highlighting the text.

The next steps are to generate, review and define themes from the coding. Using the coding in table 9.25, the following themes were characterized:

- Software: Bugs/problems/improvements, graphics/realism
- Hardware: Surroundings/hardware, Virtuix Omni
- Psychology: Immersion, knowledge acquired, metaphors, motivational effect

The subsections in the discussion will, therefore, follow the same structure.

Chapter 10

Discussion

This chapter follows the same structure as the previous chapter with the results. A discussion for each of the sections from the results is presented, and in some cases, further analysis is shown.

10.1 Survey 1

10.1.1 User demographic

For this survey, there was a lot of variety in age amongst the testers. The majority, however, were university students between 20-30 years old. Almost all of the participants were male. According to Statista, a leading provider of market and consumer data, 57% of VR/AR owners in the United States are male, and as much as 69& of people intending to buy VR/AR devices are also male. [41] This could have an effect on the results since the majority of people interested in VR/AR is currently men.

10.1.2 Difficulty of the game

One would assume that people who did not manage to take out the fire would find the game more difficult. Out of the four people who did not manage, 75% of them had a score of 3 or higher. With a larger dataset, it might have been possible to see this correlation, but there were not enough testers for that in this survey. However, there is a clear

trend that indicates that the difficulty level of the game is balanced, with most people considering it to be not to easy and not too difficult. An even distribution of people on both sides of the center bar considers it a little difficult and a little easy, respectively, which is exactly where the difficulty level should be. There is also an indication that most people manage to complete the game, which is desirable.

10.1.3 Tutorial and introductory video

An overwhelming majority understood how to play the game after seeing the tutorial. With an average score of 4.75, it is clear that the tutorial was very effective in teaching the players how the game works. This is turn saves time when testing (because I do not have to explain everything) and makes every experience more consistent since everyone is getting the same explanation. The opening scenes were also highly effective in achieving their goal, as most people strongly agreed that they were a good reminder of climate change. This raises the participant's awareness of the topic since they are again reminded of the importance.

10.1.4 Educational vs entertainment value

With an average score of 4.38, it is clear that most people had fun playing the game. The two people who disagreed with the statement both wrote comments in the survey stating that the walking aspect of the game was difficult and not very satisfying. Most likely, this had a big effect on their experience of the game. If you have trouble moving around in the game, it is hard to accomplish the other objectives of the game. Most people agree that they know much about climate change, with a good portion adamantly believing they know a lot about it. Unfortunately, most people did not learn anything new about climate change after the VR experience. With a disappointing average score of 2.44, it is clear that the experience does not provide *new* information regarding climate change, however, according to table 9.2, it does serve as a good reminder of the dangers of it. Now, it is highly likely that the low score of this question is attributed to people feeling that they already know a lot about the topic, and the basic information provided in the game is not something new to them. This is reasonable to assume since most testers in this survey were educated university students who claim to know a lot about climate change from before.

10.1.5 Suggested improvements

There were a few suggestions for improvements in this survey, and these are categorized in the table 10.1. Firstly, it is the comments regarding the walking aspect of the game (also mentioned above). This is understandable since the Virtuix Omni is often challenging to use for the first time, and many people do not fully get the hang of it before the testing is over. It is possible that the harness was not properly adjusted to their desired height or that the walking speed was different from what they are used to. However, most likely, it is a matter of getting used to the unusual way of operating the Virtuix Omni. This is, unfortunately, not really something that can be fixed without an upgraded hardware version of the Virtuix Omni. The gameplay elements that could be improved were more buckets of water and a fire inside Nidarosdomen. The buckets will be addressed in the next version, and the fire inside Nidarosdomen will also be a part of the upcoming module. As a player, however, you will take out the fire from outside of the cathedral, not inside. When it comes to the tutorial, there were suggestions about having more time for the instructions. One of the comments wrongly criticized the tutorial and claimed it did not mention you could pick up the water-buckets. This might mean that they did not catch this information and that it should be explained more clearly. To address this problem, the next version of the game will have another voice-over that will hopefully speak slower and more coherent. The opinions about the difficulty level of the game, as expected from the previous results, were mixed. This is good because it means the game falls somewhere in the middle on the scale.

Improvement category	Specifics mentioned	People
Movement	Hard to walk	2
Tutorial	More time, didn't catch all information	2
Difficulty level	Too easy/too difficult	2
Game elements	More water buckets, fire inside Nidarosdomen, weather	2
General feedback	Good game, intuitive	1

TABLE 10.1: Categorized suggestions for improvement with specifics mentioned

10.1.6 User Experience Questionnaire (UEQ)

The smaller version of the UEQ measures two higher-level meta-dimensions (pragmatic quality and hedonic quality) as well as the overall score. The scores are based on the eight questions shown in the tables above (table: 9.6 - table 9.13) The questions in the

UEQ are supposed to range from 1-7, however, in the survey given to the participants, there was mistakenly a scale from 1-5. To account for this, and to still be able to use the tools and measurements provided by the UEQ framework (such as the benchmarks), the results were converted from a scale of 1-5 to a scale of 1-7. Note that this could impact the results since the participants had fewer options than intended. The results are interpreted as follows:

- Neutral evaluation: Values between -0.8 and 0.8
- Positive evaluation: Values above 0.8
- Negative evaluation: Values below 0.8

The range of the scale is between -3 (horribly bad) and 3 (extremely good); however, in real applications, the scales are measured between -2 and 2. According to the UEQ, this is because ”It is due to the calculation of means over a range of different persons with different opinions and answer tendencies, for example, the avoidance of extreme answer categories, extremely unlikely to observe values above +2 or below -2. Thus, even a quite good value of +1.5 for a scale looks from the purely visual standpoint on a scale range of -3 to +3 not as positive as it really is.” (Laugwitz et al., 2008) [34]

Looking at the table 9.2, the standard deviation for each question is between 1 and 1.7, with question 5 (boring/exciting) and 8(usual/leading edge) being the questions with the highest standard deviation. Both of these questions are in the hedonic quality section. There also seems to be an upward trend in the standard deviation from the first question to the last, which could possibly signify that people pick more randomly as the questions go by. Overall, the mean of each question is all above 1 - inside the positive evaluation range - with the first question having an average of above 2. This question is whether the application is obstructive or supportive, and most people consider the app to be supportive. This could be explained by the emphasis on the tutorial at the beginning of the game, which supports the player in making the right decisions in the game by showing them how to play. The pragmatic quality attribute scored an average of 1.693, while the hedonic quality attribute scored 1.600. The overall mean was 1.647. This is considered a quite good score as all values are well above the 0.8 mark. Looking at the graph 9.4, the scores are well up in the green and are relatively even.

Benchmark

Even though the scores are pretty good by itself, it is also important to compare the results with other applications using the same method to determine where it stands in comparison. To do this, the UEQ provides a benchmark data set that contains data from 14056 persons from 280 studies concerning different products (such as business software, web pages, webshops, etc) It is important to note, however, that this benchmark is based on the full UEQ and not the short one because the short version is relatively new and lacks a good quantity of data. The scales do transfer relatively well over to the short version, though, and gives a decent approximation of the UEQ benchmark.

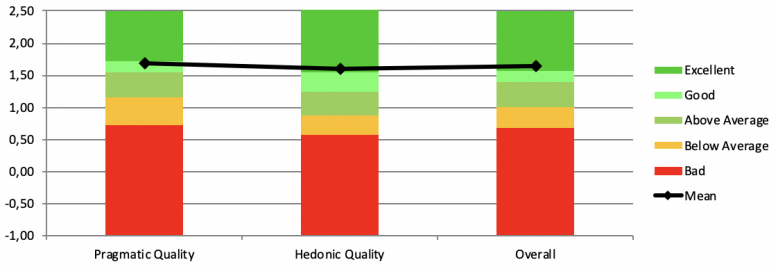


FIGURE 10.1: Benchmark

From the graph, one can see that the pragmatic quality is within the ”good” range, the hedonic quality is just within the ”excellent” range. The overall benchmark is also in the ”excellent” range.

It is important to observe, however, that the data for the benchmark is mostly for more conventional user interfaces such as websites, apps, and software and not so much VR applications. This could affect the results and make them appear better than they really are. Most people are not used to VR and do not have a benchmark standard in their mind of how VR apps should behave or look like.

Sample size

It is important to consider the sample size when making a more detailed analysis like this, and the precision of the results. The UEQ provides a tool for giving a rough estimation of how many data points are required for a given precision and error probability. These numbers are shown in figure 10.2 and are based on the standard deviation of the pragmatic and hedonic quality. As seen in the table, a precision of 0.5 and an error probability of 0.1 requires at least 11 samples for the pragmatic quality and 21 for the hedonic quality. With a sample size of 15, the requirements for the hedonic quality is

not met. The results must therefore be considered carefully, as the precision and error probability are relatively high. For more accurate results, one would have to have many times the sample size acquired from this survey.

Condition	Pragmatic Quality	Hedonic Quality
Precision=0.5, Err.Prob.=0.1	11	21
Precision=0.5, Err.Prob.=0.05	15	30
Precision=0.5, Err.Prob.=0.01	51	51
Precision=0.25, Err.Prob.=0.1	44	84
Precision=0.25, Err.Prob.=0.05	62	118
Precision=0.25, Err.Prob.=0.01	107	205
Precision=0.1, Err.Prob.=0.1	274	524
Precision=0.1, Err.Prob.=0.05	386	740
Precision=0.1, Err.Prob.=0.01	669	1281

FIGURE 10.2: An estimation of the sample size required for a given prescision and error probability, based on the standard deviation of the two categories (Pragmatic- and Hedonic Quality)

10.2 Survey 2

10.2.1 User demographic

The user demographic for this survey was largely influenced by my peers since the link to participate in the survey was posted on my social media and sent through various messaging services. Therefore, the largest represented age group is around my age, between 20-30, with some older participants above 30 too. There is a clear majority of males representing 2/3 of the participants, and 1/3 are females, with a total of 22 and 11, respectively. This is most likely because a lot of my male friends are more into gaming and likely considers the project more interesting than my female friends. The results in this survey must be carefully considered since they are acquaintances of mine and will most likely give more positive results. However, at the same time, they are simply watching a short movie of me playing and not trying it out themselves, and will, therefore, have a very different experience than if they were to try it. Most likely, they would appreciate the mechanics of VR and the omnidirectional treadmill if they tried it themselves and thereby evaluate the prototype more favorably.

10.2.2 Entertainment value

With only three people not wanting to try the game, it is clear that the game seems attractive to most people. However, a good portion (21%) of participants are neutral to the statement, and only 24% strongly agree. This indicates that most people seem to want to try it, but are not overly enthusiastic about the game - which is expected. Similar results are seen in the second statement in table 9.15 where the majority seems to think the game is fun to play. A slightly lower average score of 3.67 compared to 3.73 of the previous question might be because many people want to try the Virtuix Omni, but might not consider the game fun enough by itself to "strongly agree" with the statement. Regardless, the majority of 64% agree that the game seems fun to play.

10.2.3 Educational value

Interestingly, most people claim they do not know a lot about cultural heritage preservation. This is a stark contrast to the previous survey, where almost everyone believed they knew a lot about climate change. From the last survey, it was noted that a possible reason as to why most people did not learn much new information about climate change, was because they felt like they already knew a lot from before. In this case, however, most of the participants do not have a strong foundation of knowledge about the topic, and consequently should be able to gain some insight from the experience. This indeed seems to be the case, as table 9.17 indicates that most people learned something new with a Likert score of 3.85. Comparing the last survey where the score was only 2.44 for new knowledge, and 4.19 for the question about previous knowledge, it certainly seems to be reasonable to assume this is a factor in the very different scores - despite using a similar approach for both modules. With an average score of 3.88, it is clear that most people agree that we need to do more to protect the churches in Norway. This might indicate that the experience made an impact on many people - especially considering most people did not know a lot about cultural heritage preservation from before, but still believes more needs to be done after the experience. Even more surprising was the high Likert score (4.30) of the last question (table 9.19 regarding fire safety. Almost everyone believed they learnt something new about fire safety in Nidarosdomen. This is great and might be attributed to the fact that the whole scenario is built upon the existing fire safety of Nidarosdomen and what would happen in the unlikely event of a

fire starting there. Cultural heritage preservation on the other hand, like climate change, is a little more abstract concept and might be harder for the user to understand. The part with Notre Dame was to create emotional feedback and consider the importance of cultural heritage, while the part about the current fire safety of churches in Norway was to address one specific part of cultural heritage preservation, namely fire safety. Thus, when learning about fire safety, you also implicitly learn about cultural heritage preservation, since fire safety is one element of this. This might not have been clear to some of the users, or it was not conveyed properly in the video. Ultimately, it seems like the experience does raise awareness of the cultural heritage preservation, especially considering fire safety in Trondheim.

10.2.4 Realism

Despite the efforts to improve the graphics and realism of the experience, the Likert score of 3.39 indicates only a meager improvement from the Climate Quest experience with the same question in table 5.9 where the score was 3.27. There is a slight majority of 51% that believe the graphics are good, and 21% that believe the opposite; the remaining are neutral. This is unfortunate since it means the efforts to improve the experience in terms of graphics did not make much of a difference. With a score of 4.36, however, it is very clear that the VR treadmill makes the experience more realistic. More importantly, it seems that almost everyone believes that they would remember the experience better if they were physically running in VR compared to using regular controllers. It is important to note that these people did not actually try the experience physically, however, according to numerous studies on the relationship between physical activities and the brain, there is clear evidence of the many benefits on cognitive function physical activity has. In a paper from the Frontiers in Psychology, results of cross-sectional and epidemiological studies showed that PE enhances cognitive functions in adults and "improves memory abilities, the efficiency of attentional processes and executive-control processes." (Mandolesi et al., 2018) [42]

10.2.5 Tutorial/opening scenes

With an average Likert score of 4.85, it actually beat the previous score from the last survey despite people not playing the game physically. This might also be the reason for

Improvement category	Specifics mentioned	People
Buckets	Bigger buckets, pick up buckets closer, use a pump instead, too many buckets	4
Connection to introductory movie	Didn't see the connection	2
Running	More running, less running, obstacles	3
Graphics	Better fires, smoke effect/feedback	3
Nidarosdomen	Tour through Nidarosdomen, collapses	2
Sounds	Too harsh water sound, crackling sound	2
Other	Fire truck, map, more levels and features	2
Positive feedback	People using the section for positive comments	11

TABLE 10.2: The opening scenes (with fires in Notre Dame) reminded me of the importance of cultural heritage preservation

the high score because people who actually played the game and made mistakes might attribute those mistakes to a lacking tutorial, while people who just watch me play will not make the same mistakes and think they understood everything. That might not have been the case if they were to play the game themselves. The opening scenes also seem to be effective with a score of 4.36, although with a slightly lower score than the corresponding question in the previous section (Score: 4.56, table 9.2). The lower score is mostly attributed to the one outlier who strongly disagreed with this statement, while everyone else either agreed or was neutral.

10.2.6 Suggestions and other comments

The average rating of the game was 3.76 stars, which is a reasonably good score. Interestingly, there was a significant increase in the number of comments and feedback for this section compared to the previous ones with a total of 27 comments. The most likely reason for the increase in comments is that most people stay at home during the COVID-19 and have a lot of spare time to answer the questions more thoroughly. When testing in the lab, there is often a lot of other activities and VR experience for the participants to try out. There is also a time constraint of a few hours, so they often rush a little to finish the surveys to continue to other activities instead. A lot of the comments were just positive feedback, but many also included valuable feedback. The feedback is summarized in table 10.2 and shows, amongst other things, that many people have opinions regarding the buckets in the game. There were mentions that there should be bigger buckets with more water and that the player must be closer to the bucket to pick it up. This could definitely be an option, but since most people already struggle a little

the first time running on the Virtuix Omni, it is easier and less stressful to be able to pick up the buckets without physically reaching out for them. It may look stupid on a video, but when testing it in person, it feels more natural. Another suggestion was to use a pump instead of buckets lying around, which is an interesting idea and would certainly feel more natural than random buckets. The last point regarding the buckets was that there were too many of them in the game. Because the comments on previous versions wanted more buckets, there was added a lot of buckets in the game, perhaps even overcompensating a little. A few people did not see the connection from the game to the introductory movie. This is understandable since the connection might not be obvious since the game itself does not focus on the specifics mentioned in the video, like the sprinkler system and connection to the fire department. This was rather seen as a way to educate the participants on the current state of the churches in Norway, which is a big part of Norway's cultural heritage. Fires are a potential risk for these churches, and to experience this first hand in VR might make the participants remember the importance of preserving them by, for example, improving fire safety (which was the focus of the video). There were also comments about the running in the game, where some people wanted more running and some people a little less running. A suggestion for various obstacles to run around was mentioned, and could as an example be parts falling of Nidarosdomen. Although very difficult and time-consuming, making Nidarosdomen interactive and respond to the fire better would certainly be a great addition to the game. The graphics were again mentioned as an improvement, despite the efforts to revamp them after previous feedback. In the version where there is a fire in the area around Nidarosdomen, there are smoke effects on the fire with both light and dark smoke combined with sparks. In this module, however, where Nidarosdomen itself is on fire, there is another particle emitter in use without these details. In the comments, there is a specific suggestion to improve the fires with smoke effect, and it would not be complicated to reuse parts of the previous emitter in the previous section to accomplish this. There are also a few suggestions regarding Nidarosdomen and how it would be nice to have a tour around Nidarosdomen as well as the aforementioned interactive collapsing of the cathedral. This would certainly be nice to have included in the game; however, it is out of the scope of this project. The sounds of the game were also mentioned in the comments, specifically mentioning the water sound and the crackling sound of the fire. For the water sound, the comments included the fact that it is too harsh, and in the long run, it might be annoying. This is a fair point, and together with the crackling

sound of the fire should be addressed. Lastly, there were other mentions that, although very interesting and unique features are sadly out of scope for this project. This includes using a fire truck, a map, and more levels and features.

10.3 Interview with VR expert

10.3.1 Software

A theme in the interview was the software of the game itself. There were a few problems during the testing; most notably, the participant felt it was tricky to know how much you can reach with the water. When he was aiming towards the top of the cathedral, it was hard to know if he was actually hitting the fire or not. This is, of course, a little subjective; however, there is most likely also a fault in the software. The hitboxes for the flames are simple squares, while the animations are not, and there isn't any indicator of how much water you have applied to the specific flame node. The boxes should cover most of the animation of the flame; however, with certain angles, this is not always the case. Also, from the viewer's perspective, it might be hard to hit flames that are on the top of the cathedral from such a steep angle because you can hit walls and other parts of the cathedral first. When it comes to other parts of the game, one must consider the fact that the game's trees have a cylindrical collider while the actual tree mesh is a little bent. This choice is made due to performance, since a perfect mesh-collider is expensive when rendering that many trees, however, it might be weird for the user when the water is hitting the air next to the tree, and the water bounces back. Another issue he faced was that he was stuck between a bucket and a grave. This is possible because both the bucket and grave have colliders attached to them, preventing the player from walking through them; however, that can be frustrating for the player when he is stuck. A solution to this would be to remove the collider for the bucket, although you would then have to write some new logic to handle the interaction between the player and the buckets. Lastly, he mentioned the lack of a time indicator but later explained that thinking metaphorically, this makes sense.

Another part of the software is the graphics and realism of the game. Although not explicitly asked in this interview, informant mentioned it a few times. Specifically, he really liked the view of the cathedral, although he did not see the game itself as very

realistic. The reason for this was because the player could go close to the fire without dying. In real life, it would be impossible to be even 20 meters away from such a fire, let alone stand right next to it. He therefore took the experience as a game instead of a simulation and was pleased with the outcome.

10.3.2 Hardware

The second theme of the interview was regarding the hardware, specifically the Virtuix Omni. The participant was getting tangled in the cable for the HMD headset hanging from the VR stand and hitting the wall physically when reaching out to pick up buckets. This obviously breaks the immersion a little and can be frustrating to experience; especially since you will lose precious time that you could spend taking out the fire. This is easily fixable by moving the Virtuix Omni a little bit away from the wall and properly setting up the VR stand so that the cable does not get tangled. However, it did not seem that important since he said he was so immersed and "fully into the game." For the running part with the Virtuix Omni, he commented that the movement was a little difficult. The aforementioned case with getting stuck obviously did not help, but he generally thought the Virtuix Omni worked really well. He felt like the speed he was running in real life did not match the game's speed properly but compared this to a metaphor of a firefighter running with hoses to get there, which would be a similar experience. The overall impression of the use of Virtuix Omni in the game was very positive, and he thought it worked well. He mentions that he was more focused on the tasks of the game and thought the game was very immersive. This can indicate that the Virtuix Omni plays a part in the immersiveness of the application in a positive manner.

10.3.3 Psychology

The last theme that was present in the interview was psychology, which in this case involves immersion, the knowledge acquired, and metaphors in the game. Before the interview, I had not considered metaphors as part of the experience, nor was it part of the development stage of the game, but I do see the reasoning behind it. The first metaphor he talks about is the bucket metaphor, where you realize how difficult it really is to take out a fire. Even with the help of professional firefighters and proper equipment, it can sometimes feel like you are pouring small buckets on an enormous fire. This is especially

true with cultural heritage buildings as there is elevated importance of keeping artifacts and the buildings themselves as intact as possible. The second metaphor is regarding the difficulty of running, and is compared to the difficulty firefighters experience when running with hoses trying to get close to the fire; it displays a similar level of difficulty. Lastly, he encourages people to reflect on what happens in the game to understand what is really going on.

Another coding that is part of the psychology theme of the interview is the immersiveness. The VR expert mentions several times how immersive the experience and how he was ”fully into it”. This is most likely attributed to the combination of VR and Virtuix Omni and the gamified experience. He mentions he was very focused on the objective of the game, which is great. The goal of the experience is ultimately educational, and being properly immersed will help solidify the experience in memory.

Lastly, there is a coding for the learning part of the application. The informant said the introduction was interesting and very informative, even shocking. He was not aware of the poor state many of the churches are in Norway, and not how common forest fires are becoming with the rise of climate change. The videos were seen as a good tool for communicating these issues, and he really liked the charts that are shown after the climate change experience where you can see how you, as an individual, can help combat climate change. In the end, the experience taught him something new about the issues, which is the goal. Emotionally, he would respond better to a city he knows compared to a generic one, and he was disappointed when he could not stop the cathedral from burning down.

10.4 Limitations

The study has a number of limitations, both for the questionnaires and interviews. There are a few things specifically to note regarding the data of the questionnaire. Firstly, since the Virtuix Omni and VR itself is fairly complex and requires much setup for the user, I have interacted a lot with the testers to make sure they understand how to use the application and relevant hardware. These interactions might inadvertently impact the results of the questionnaires. This relates to the ”Principle of Interaction between the Researcher and the Subjects” from Klein and Myers (1999) [43]. Also, since

VR is still a relatively young and growing field of technology, most people that test the application have not experienced VR before - especially not with an omnidirectional treadmill. It is therefore important to note that this can affect the results; either the user is shocked at how fascinating the technology is and gives positive scores regardless of how the application itself was, or, they might be overwhelmed with all the new input and emotion and/or stress when testing the treadmill in front of a lot of other people and give a more negative score. This bias relates to the ”Principle of Suspicion” in the aforementioned paper from Klein and Myers (1999) [43]

The application is also tested on specific locations in Trondheim (Gamle Bybro and Nidarosdomen). For some people, this might have a larger or smaller impact emotionally - especially comparing testers that are from Trondheim or live in Trondheim against people who are visiting from other countries.

For the interview, a thematic analysis is conducted, and it is important to note that thematic analysis is quite subjective and allows a lot of flexibility in interpreting the data. There is also the risk of missing nuances in the data. The VR expert in the interview was also the only participant that was able to test both modules of the application; cultural heritage and climate change. It is therefore difficult to say whether the act of combining the two modules into one application had a significant effect or not. Most likely, there is little difference in having two separate applications for the issues, however, it makes it easier for the participant to see that, in the case of Norway’s churches, the issues are correlated.

Lastly, the final survey is done remotely (due to the COVID-19 outbreak) and does not include anyone physically testing the Virtuix Omni, but instead includes watching a gameplay video of the experience and answering questions thereafter. The participants have to imagine how the experience feels because they are not actually participating themselves. This could implicate the results, especially regarding questions that rely on the immersiveness that the VR provides.

Chapter 11

Conclusion

The 2017 report from KA [3] described the current state of the churches in Norway and outlined the risks of climate change and potential fires for the churches. Many of the churches are not well prepared for neither fires nor the many consequences of climate change (such as higher temperatures, more frequent rainfalls, and avalanches, and rise in sea level). The potential risk for damage or even destruction of these churches threatens Norway's cultural heritage. The Fire Quest application takes these serious issues into account and serves as a single, combined VR experience, all within the same virtual environment (Nidarosdomen in Trondheim, Norway). The VR experience features two modes regarding Cultural Heritage and Climate Change, respectively, with distinct, yet familiar goals of taking out the fire that has started in the area. In the first, one is tasked to take out the forest fire that has started due to climate change, while in the latter, the focus is on the preservation of the cultural heritage through increased fire safety of Norway's churches. In both scenarios, there is a fire in, or around Nidarosdomen cathedral, and the objective is to extinguish the fire. Both experiences also include educational videos from real-world scenarios regarding each topic, where recent events such as the Notre Dame fire and Australia's forest fires are presented.

11.1 Comparison

When comparing the Fire Quest with the related work in the previous chapters, there are a few similar categories, namely: the use of fire, fire safety, story, climate change,

cultural heritage, and whether the application is using a physical form of movement in VR. The Trondheim VR Climate Quest obviously focuses on climate change and uses the omnidirectional treadmill, Virtuix Omni, for movement in VR. It does not engage the user in any form of a story, nor does it include any of the other areas of focus like fire, safety, or cultural heritage. The Standford OAE takes the user on a journey showing different locations with interactions happening with a narrator explaining each detail. The focus for this experience is also on climate change; however, it does not include any movement in VR, or anything regarding fire or cultural heritage. The experience that does include fire is the tunnel evacuation, where there is also a safety aspect involved. For this application, there is another type of treadmill used, the Cyberith Virtualizer, which works similarly to the Virtuix Omni. The MediaEvo application focuses on cultural heritage and also shows a lot of explanatory videos and stories as the participant moves around the ancient city. Instead of using a treadmill for movement like some of the other experiences, MediaEvo uses the Wii Balance Board to measure which direction the user leans towards and move the virtual character thereafter. Lastly, there is the Fire Quest application developed in this thesis, where all the aforementioned categories are included. There is a story told with the introductory videos, and fire safety combined with cultural heritage is present in the one mode of the application. While both modes have fires in the same virtual environment and use Virtuix Omni for movement, the second mode focuses on climate change. The comparison of all applications is seen in table 11.1.

	Fire	Story/video	Safety	Climate change	Cultural heritage	Movement in VR
Trondheim VR	-	-	-	X	-	X
Stanford OAE	-	X	-	X	-	-
Tunnel evacuation	X		X	-	-	X
MediaEvo	-	X	-	-	X	X
Fire application	X	X	X	X	X	X

FIGURE 11.1: Comparison of the fire application with the applications explained in the related work

11.2 Contributions

- Combined two important issues, Climate Change and Cultural Heritage, in one VR application
- Produced an educational game featuring the omnidirectional treadmill, Virtuix Omni

Many applications and VR experiences focus on issues such as climate change and cultural heritage; however, this is the first to combine the two. As evident from the KA's report [3], the issues are closely related considering the current and future state of the churches in Norway. Nidarosdomen is a good example of a building that faces both these issues, thus the major contribution for this thesis is the combined application within the familiar environment of Trondheim city. There are also few applications yet that make use of an omnidirectional treadmill such as the Virtuix Omni, so the Fire Quest is a good addition to the increasing arsenal of experiences available for the Omni, especially considering its educational value.

11.3 Research questions

The research questions are listed below and summarized to provide an overview of the conclusions:

R1: *Using the feedback from the Climate Quest application and related game theory, what are the requirements for a new module with fire in Trondheim? Specifically focusing on the theory of game design and criteria such as the current usability, realism, engagement, and immersion of the application.*

The development of the application followed an incremental approach where the initial background studies were completed for a similar app regarding climate change in Trondheim and the rising sea level. These studies, combined with a theoretical analysis of the game, formed the requirements for the Fire Quest application. The requirements, as well as the priority and the completion status, are seen in table 11.1.

As evident in the table, almost all requirements are implemented. The remaining requirements include random spawning of fires and a feature that the fire should be sensitive

	Requirement	**Priority**
✓	The experience should feature both Climate Change and Cultural Heritage	High
✓	There should be a menu to choose which module the player wants to experience	High
✓	The game should use both VR controllers and the Virtuix Omni treadmill for the interaction	High
✓	The player should be able to interact with the fire by shooting water at it	High
✓	There should be fire that propagates with a certain degree of randomness	High
✓	The fire should be able to propagate in buildings and trees, not just the ground	High
✓	The player should be able to eradicate the fire to win the game	High
✓	There should be a video tutorial explaining the controls and game mechanics	Medium
✓	There should be hidden elements in the map such as water buckets that the player can interact with	Medium
✓-	There should be fires spawning from random or different locations	Medium
✓	There should be educational videos explaining the topic of cultural heritage and climate change with examples from real life.	Medium
✓	The player should be able to roam the environment freely, not a linear path	Medium
✓	The environment should be more interactive with moving grass and trees	Low
-	The fire should be sensitive to the wind direction and speed	Low

Table 11.1: Caption

to wind direction and speed. Both of these requirements were actually implemented but were scrapped during the development stage because it proved difficult to provide a consistent enough experience for the testing. With random spawning locations, the fire would spread so different each time that it would be a completely different experience, with some players finding it way too easy and some too hard. Likewise, the sensitivity and randomness to the wind made the experience very different. Therefore, it was decided to leave it out of the game. There is some randomness to the fire propagation at the moment, and fires do spawn from different locations; however, it is still generally the same experience and difficulty for each player.

R2: How can VR together with the Virtuix Omni be utilized to raise awareness about climate change? Specifically looking at forest fires and how climate change is increasing the amount and intensity of fires around the world.

The Fire Quest raises awareness of climate change through the introductory video and the VR experience itself. The posters that are visible on the wall after the experience is completed presents specific efforts individuals can undertake to contribute to the fight against climate change. The key findings are summarized below:

- Most people already know a lot about climate change and forest fires; it is a familiar topic for many
- The participants did not learn much new information regarding climate change, most likely because most are already very familiar with it
- The experience did, however, serve as a good reminder of the dangers of climate change
- A VR expert believes it is good to be shown what your contribution to climate change as an individual can be (from the posters on the wall).
- The User Experience Questionnaire proved that the pragmatic and hedonic quality of the experience is appropriate
- Although a lot of people find it difficult to run with the Virtuix Omni, the running in VR provides more immersiveness in the experience
- The experience is generally seen as fun to play

R3: How can VR together with the Virtuix Omni be utilized to raise awareness about cultural heritage preservation? Specifically looking at maintenance as well as safety measures taken to prevent a fire from starting.

Similarly to the climate change mode, the cultural heritage mode features a video and a VR experience to raise awareness. The key findings are summarized below:

- The topic of cultural heritage is relatively unfamiliar to a lot of people
- The participants learned something new from the experience about both the cultural heritage preservation in Norway and especially about the fire safety of Nidarosdomen
- After the experience, most people believe we need to do more to protect Norway's churches
- Although a lot of people find it difficult to run with the Virtuix Omni, the running in VR provides more immersiveness in the experience. It is also seen as more realistic
- The participants believe they would remember the experience better using the Virtuix Omni
- The experience is generally seen as fun to play

11.4 Future work

This section contains improvements to the Fire Quest and potential future topics for further research.

11.4.1 Improvements

Firstly, the Fire Quest still has a few bugs that should be addressed. These are listed below:

- The player should not be able to get stuck between objects in the scene

- The hit-boxes of various objects should be more accurate, so the player doesn't shoot water right next to the object and still see it bounce off the object.

There are many potential improvements to the experience as well, and many of these have been suggested by other people during the user testing, questionnaires, and interviews. Below are some of the more prominent suggestions:

- The player should not be able to go very close to the fire. There could potentially be health points related to the player, or one could immediately lose if one walked into the flames
- Instead of water buckets, there could be a well or a firetruck that you would use to refill the water supply
- Improve the sounds in the game, specifically the water and flames
- More realistic graphics and with physics related to the deterioration of the building
- Better feedback from hitting the flames (such as smoke/steam coming out, and decreasing the size of each fire node in relation to its health)

11.4.2 Further research

Further research could be realized using AR in the actual location (Nidarosdomen, Trondheim). This would allow the participant to see how a fire would enfold in real life, and one could get a better and more realistic picture of the consequences. At the moment, there is no way for the participant to go inside the cathedral either, and this could be realized using either AR or VR.

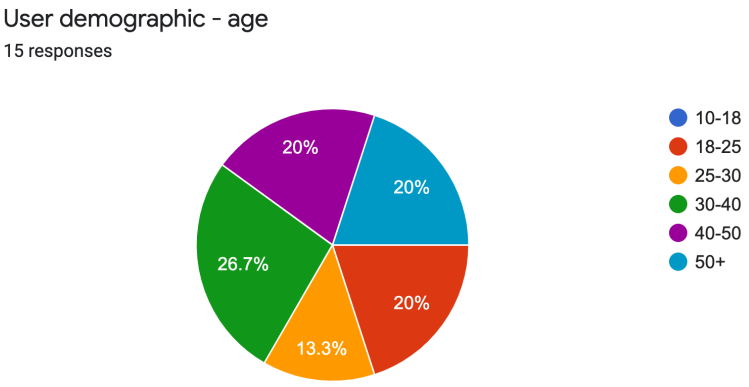
In addition to this, further research could be completed in other locations or cultural heritage sites. To make the experience more accessible, one could develop it with more affordable hardware, or even support a mobile experience through AR on capable smartphones.

Appendix A

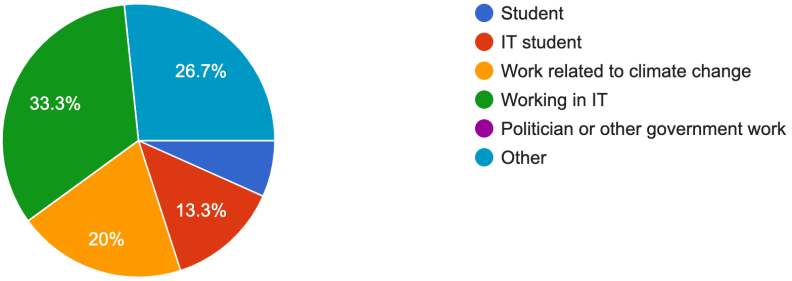
Questionnaires

A.1 Questionnaire 1

A.1.1 General information

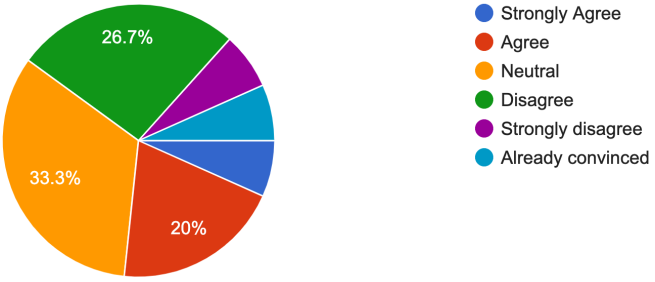


User demographic - occupation
15 responses

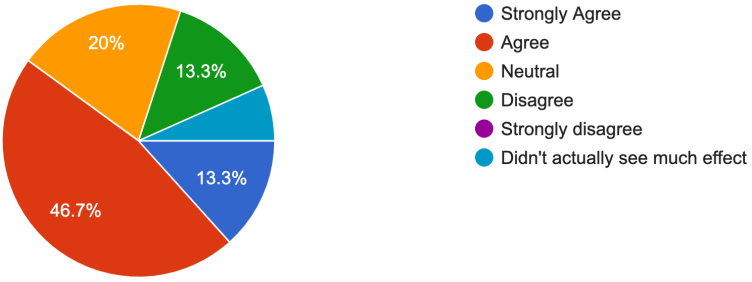


A.1.2 Attitude change

This experience motivated me to make changes in my life to act on climate change
15 responses

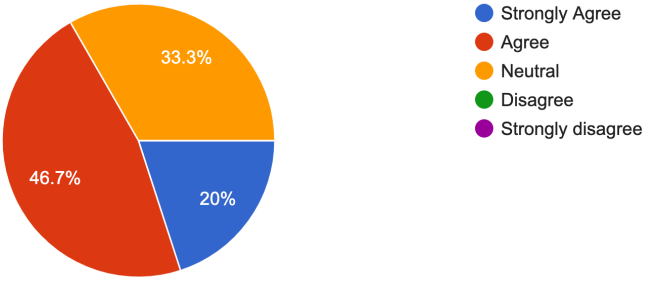


Seeing the effects of climate change first-hand made a bigger impact on me that it would if I was reading/hearing about it
15 responses



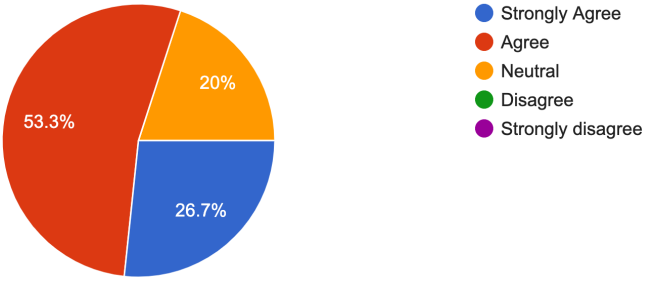
I think VR is a good tool to facilitate attitude change regarding climate change

15 responses



I think VR is a good tool to facilitate attitude change in general

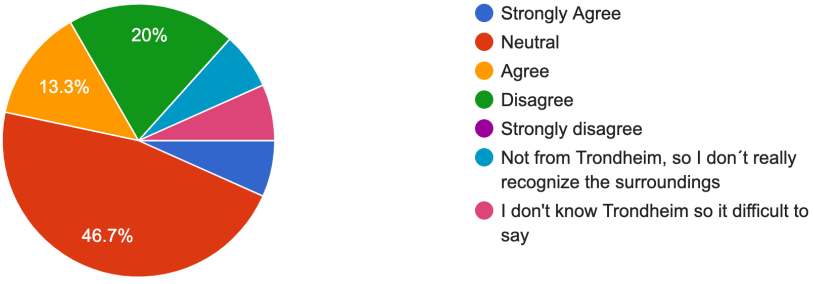
15 responses



A.1.3 Immersion

I felt like I was actually in Trondheim

15 responses



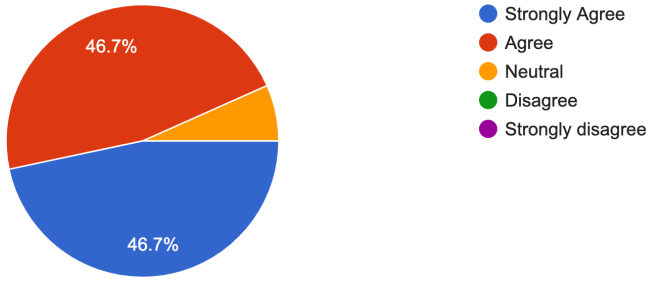
I felt the effects of the rising sea level stronger in a city I know, such as Trondheim, compared to a generic city

15 responses

A.1.4 Usability

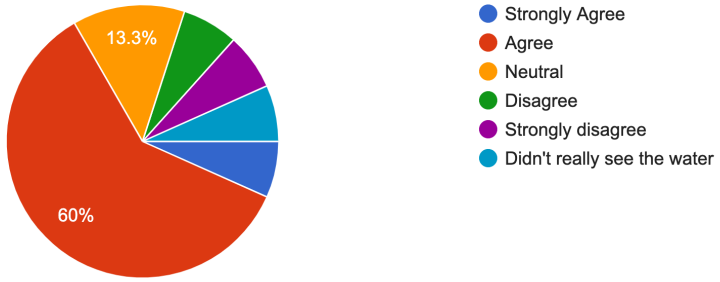
It was easy to understand what to do in the game

15 responses



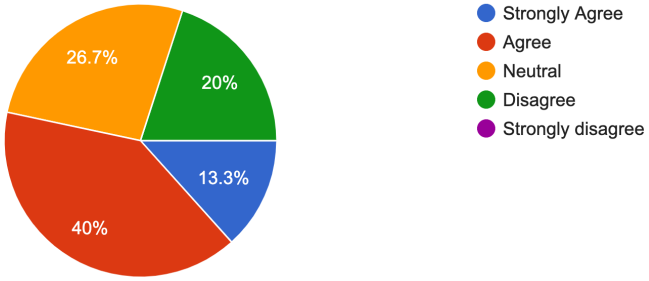
I understood the connection between the sea-level and my actions (removing cars, chimneys and CO2 molecules) in the game

15 responses



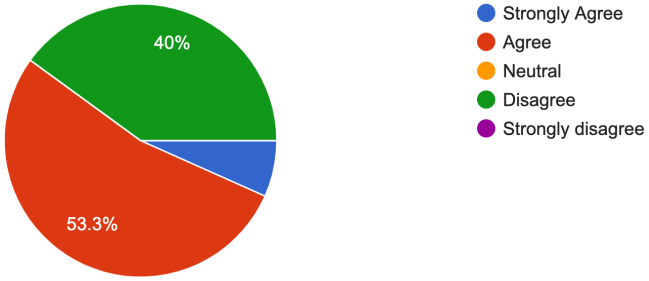
The realism of the experience could be improved to provide a better experience

15 responses



The graphics of the experience were good

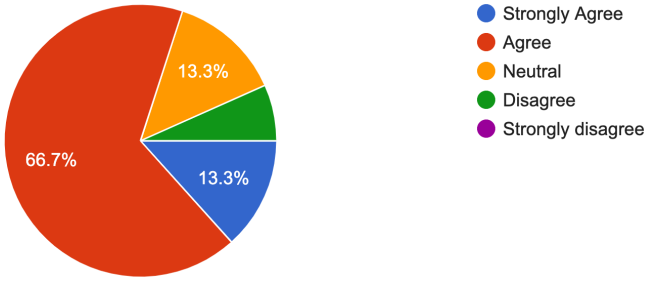
15 responses



A.1.5 Continued work - fire

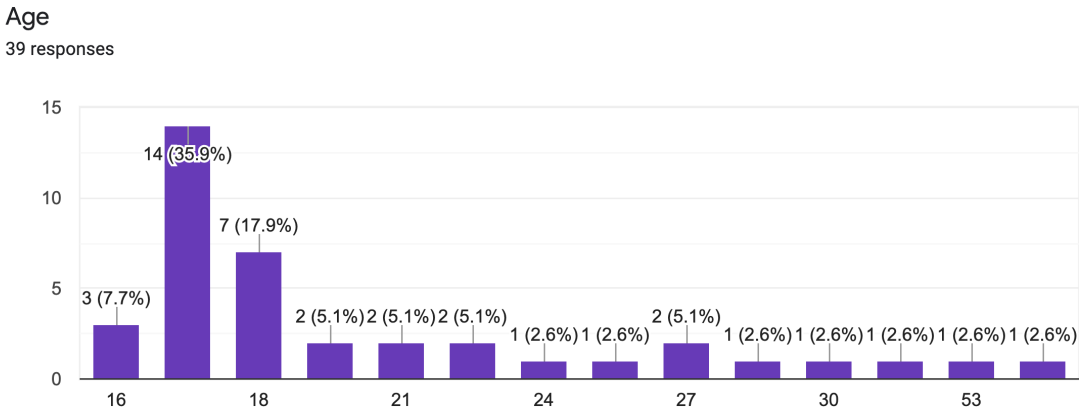
I think it would be interesting to have a similar experience with FIRE in Trondheim (due to climate change) instead of rising sea levels

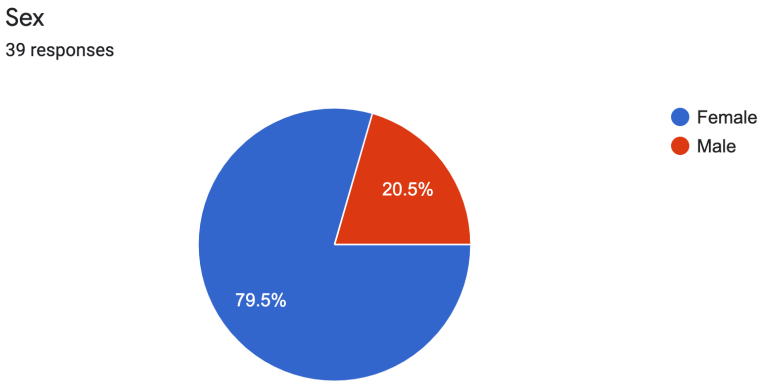
15 responses

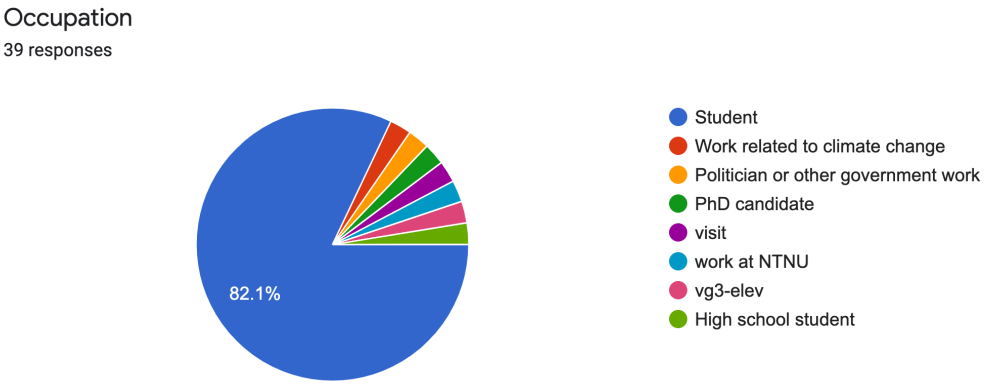


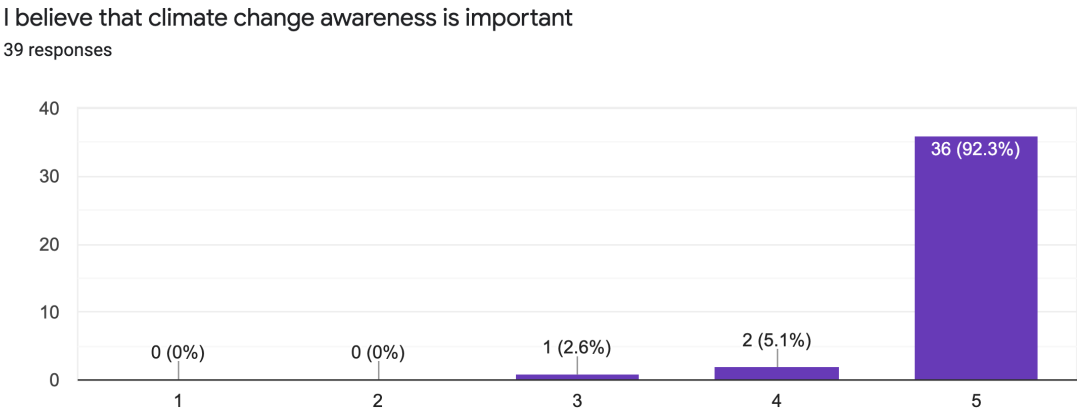
A.2 Questionnaire 2

A.2.1 General information

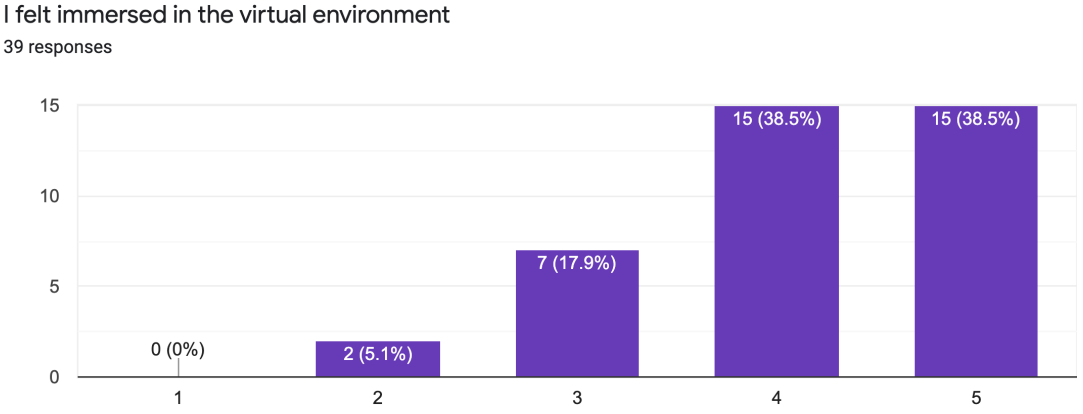






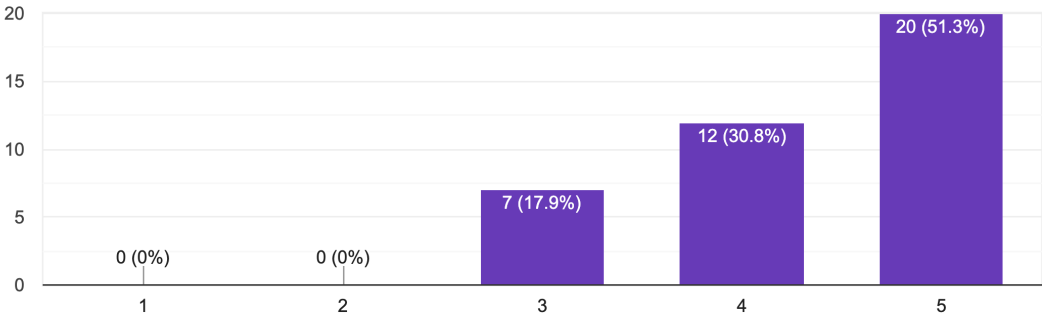


A.2.2 Previous application: Climate Quest



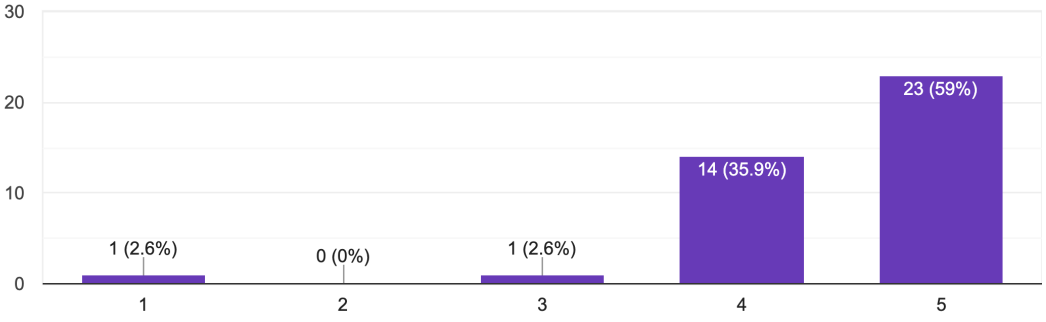
I feel more immersed when I'm physically running in VR

39 responses



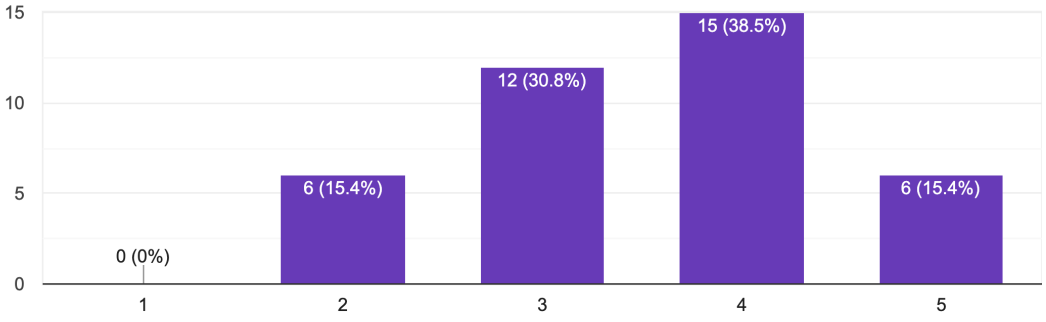
It is easy to understand what to do in the game

39 responses



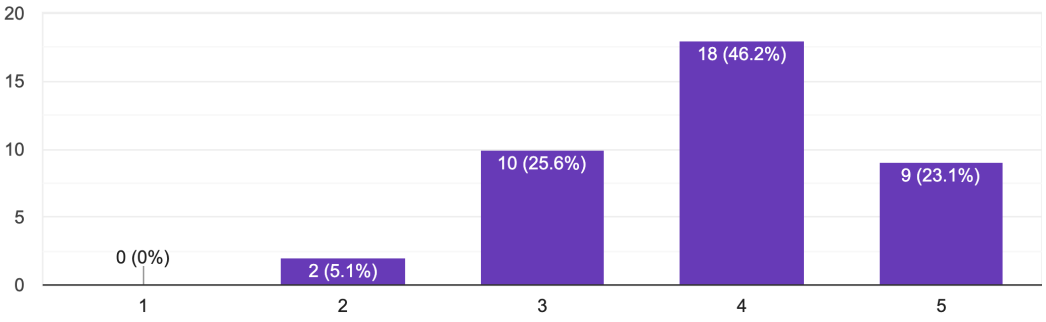
The graphics/realism could be improved

39 responses



Seeing the effects of climate change first-hand in VR made a bigger impact than reading about it

39 responses



Suggestions for improvement

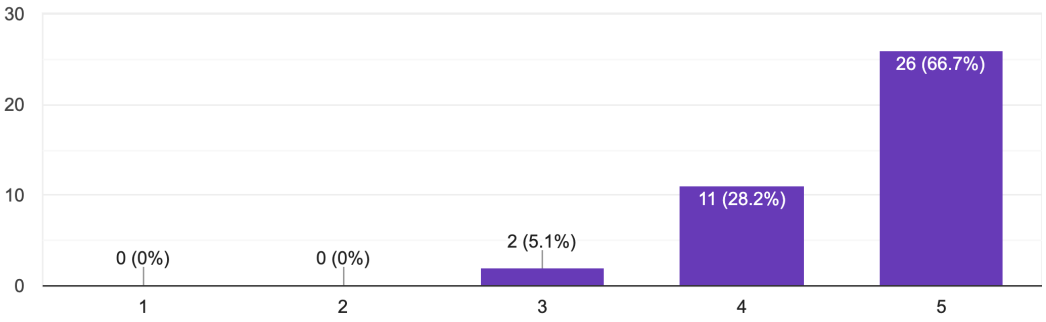
11 responses

More bird sounds
grafikk , graphics
bedre kavlitet og letter å bevege seg
i dont know
no sorry
Nothing special I can think of
Improve accuracy of shooting, implement more audio cues and improve the textures and overall graphics.
Before starting the game, having some tutorial about game will be nice.
grafisk kunne det blitt bedre fordi det tar vekk litt den følelesen av det er virkelig hvis det er dårlig/ikke ekte grafikk
Generelt miljøet
Even better graphics

A.2.3 Climate quest - Fire

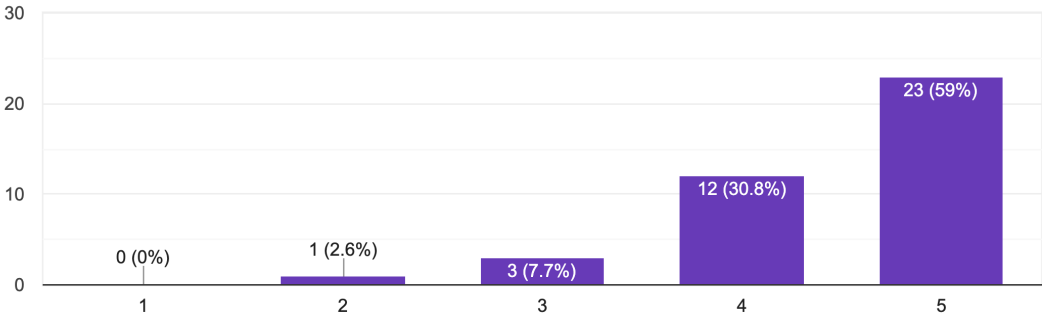
It would be interesting/educational to experience Trondheim on fire due to climate change/forest fire

39 responses



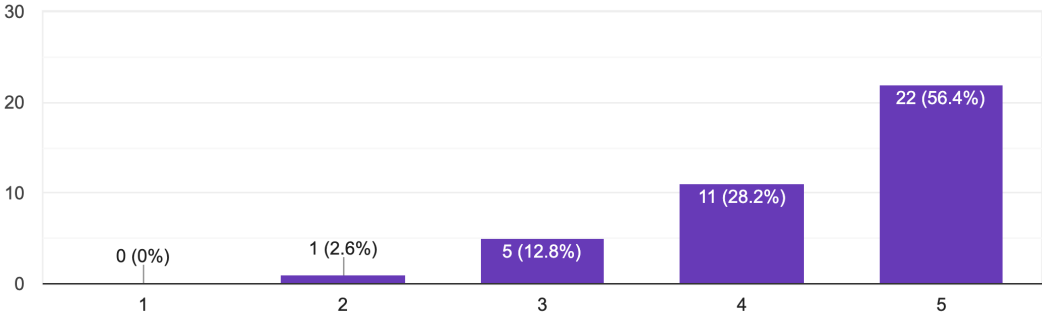
It would be interesting/educational to experience specific cultural heritages (with more emotional attachment) on fire

39 responses



It would be interesting/educational to experience safety procedures during a fire in Trondheim

39 responses



A.3 User testing

A.3.1 Notes from 28.01.20

These are the notes for the user testing 28.01.20. Most of the participants were 13 year olds.

1. pers

- Fikse så man kan gå i gjennom gress
- Veldig gøy
- Bra spill
- Litt for vanskelig, må ha mer health

2. pers

- Hadde recommenda det
- Flere oppdrag
- Vanskelig å finne ut av hvor vann bøttene er
- Bra spill

3. pers

- Kan ikke gå over flammen
- Mer sensitiv løping
- Vannbøttene var langt unna
- Anbefales

4. pers

- Gå lengre for hvert skritt

- Kult spill

5 pers

- Burde kunne gå fortere
- Veldig gøy å slukke flammene
- Kan ikke gå over flammen etter den er ferdig

6 pers

- Må treffe bøtten og ikke vannet
- Bygningen brenner i stedet
- Bøttene er nærmere eller mer vann i dem

7 pers

- Veldig interressant og annerledes
- Likte å løpe i Omnien
- Brann i bygning

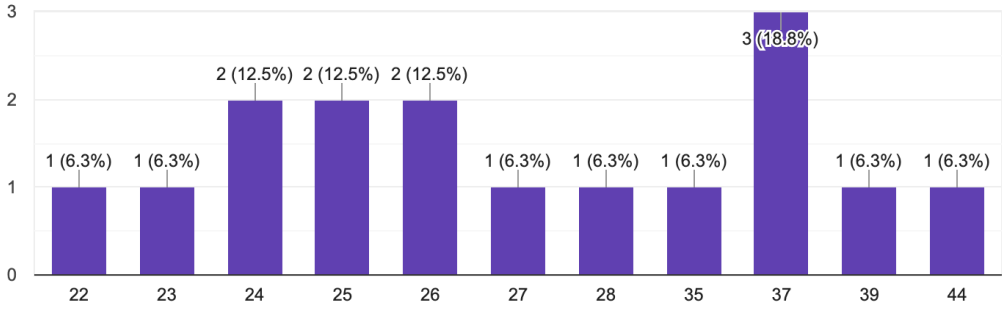
8 pers

- Veldig bra spill
- Lettere å lære seg sånt med tutorial - mangler tutorial
- Ville ha flere bøtter (litt vanskelig å finne) og ville gjøre at man må være nærme bøttene for å plukke dem opp

A.4 Fire application - Climate change

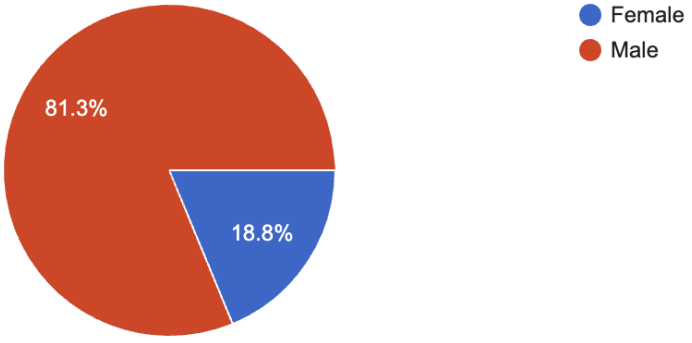
Age

16 responses



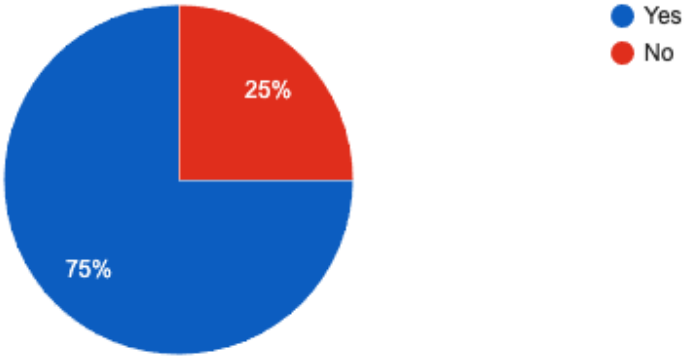
Sex

16 responses



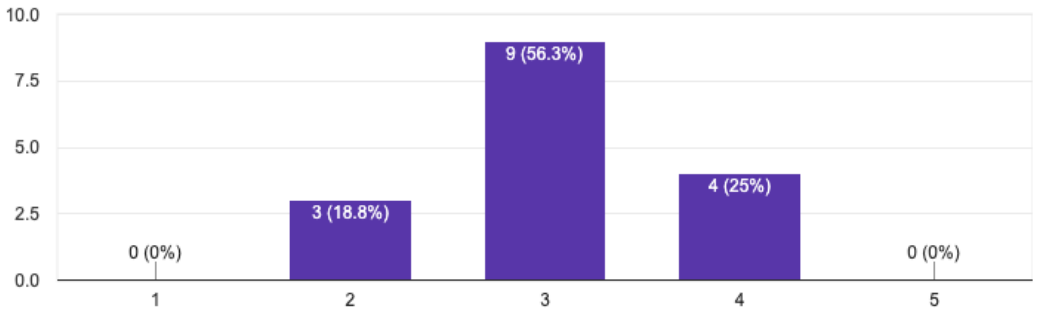
Did you manage to take out the fire in time?

16 responses



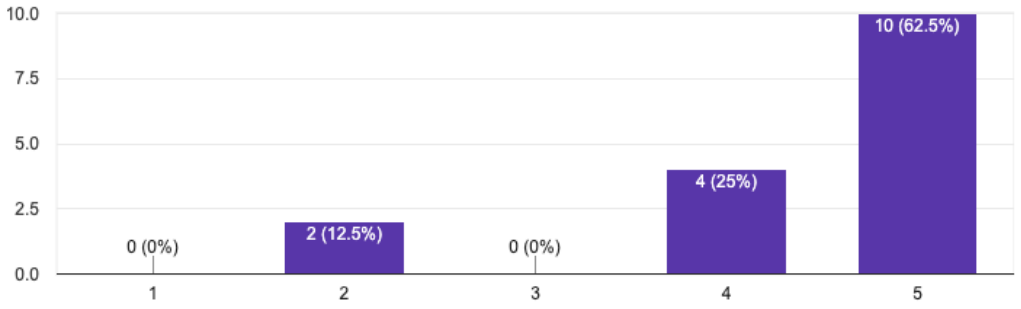
Difficulty level of the game

16 responses



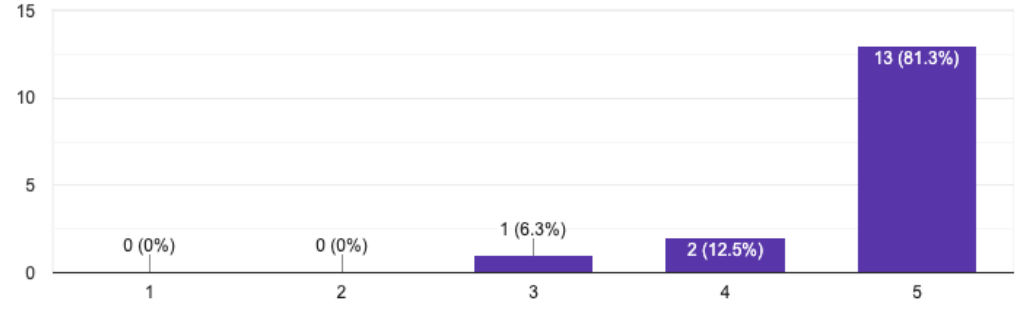
I had fun playing the game

16 responses



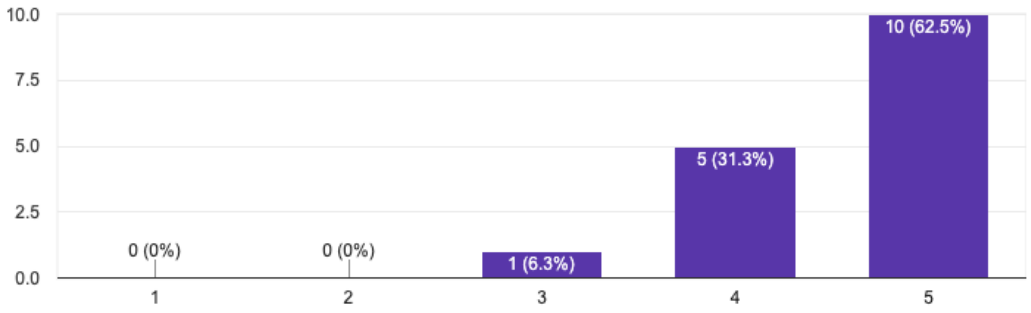
I understood how to play the game after seeing the tutorial

16 responses



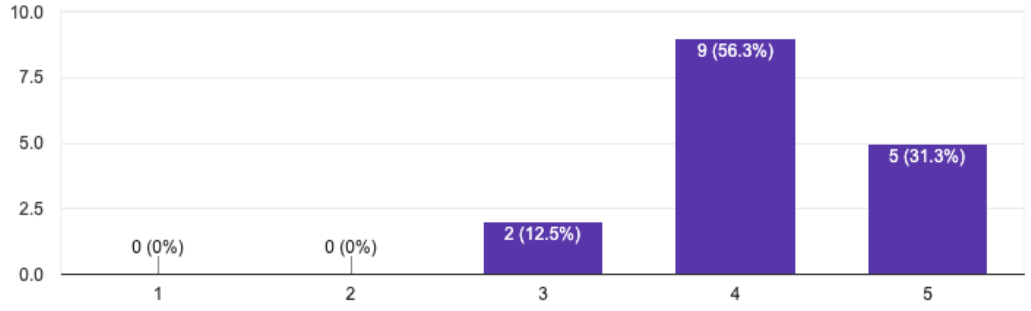
I think the opening scenes (with fires in Australia) were a good reminder of the dangers of climate change

16 responses



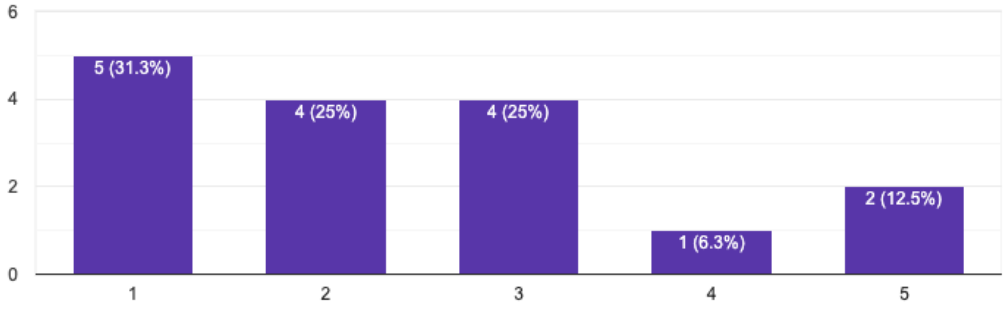
I know a lot about climate change

16 responses

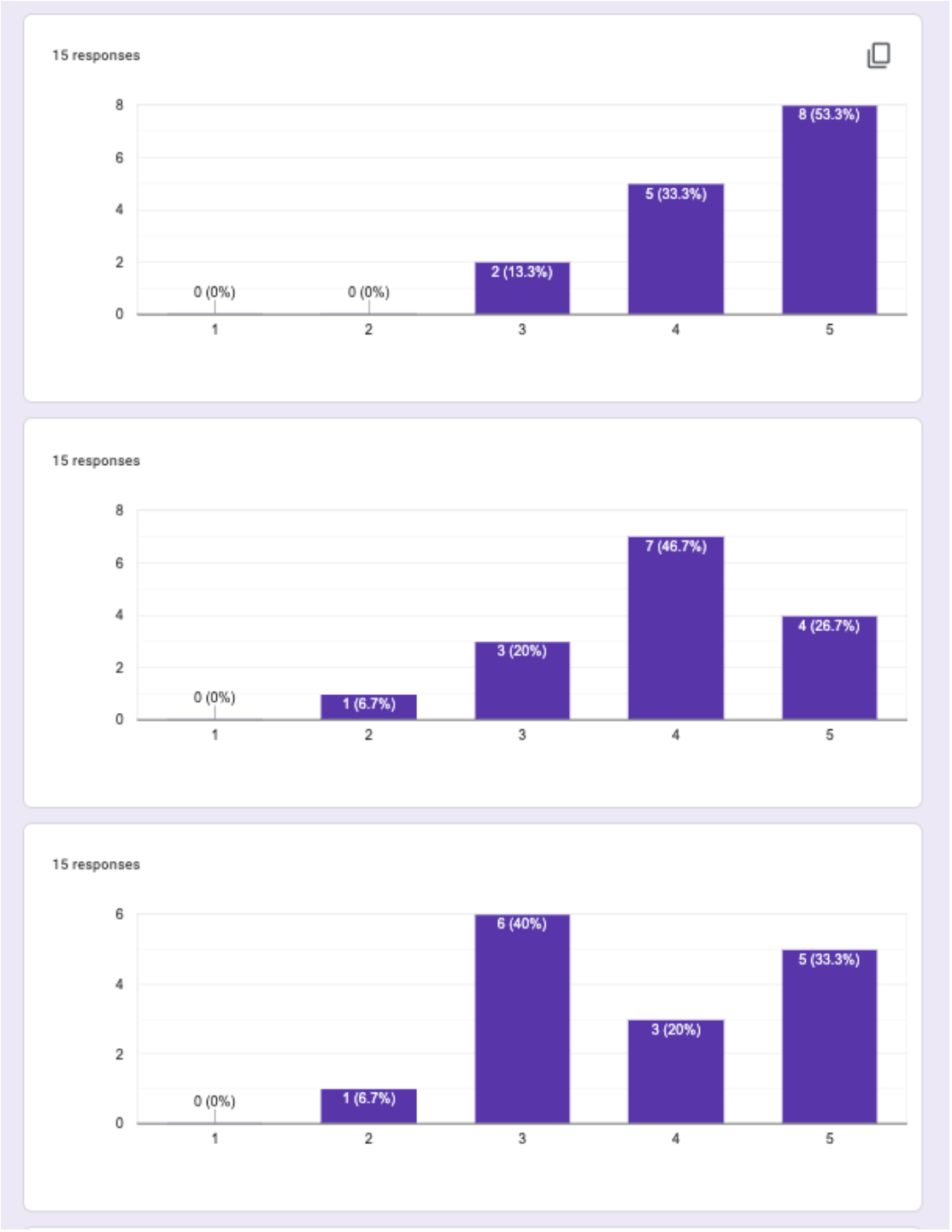


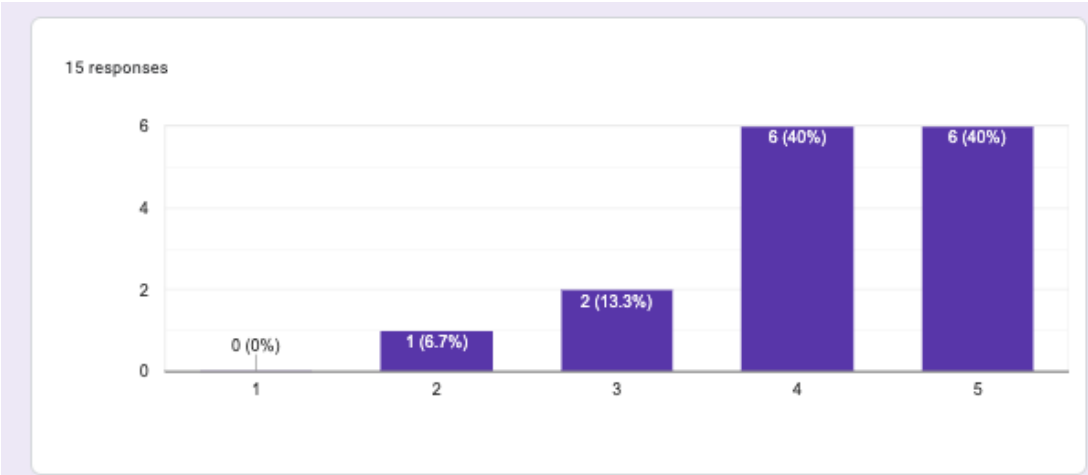
I learnt something new about climate change after the VR experience

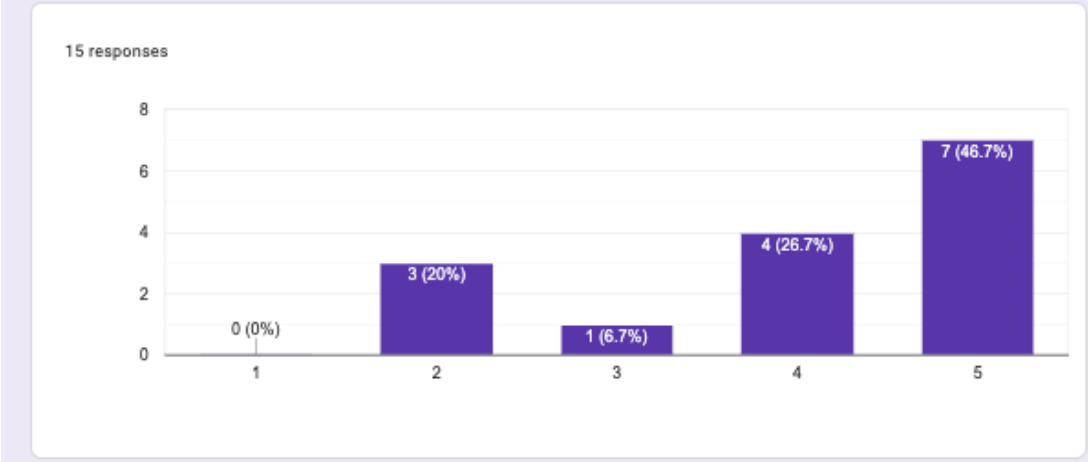
16 responses

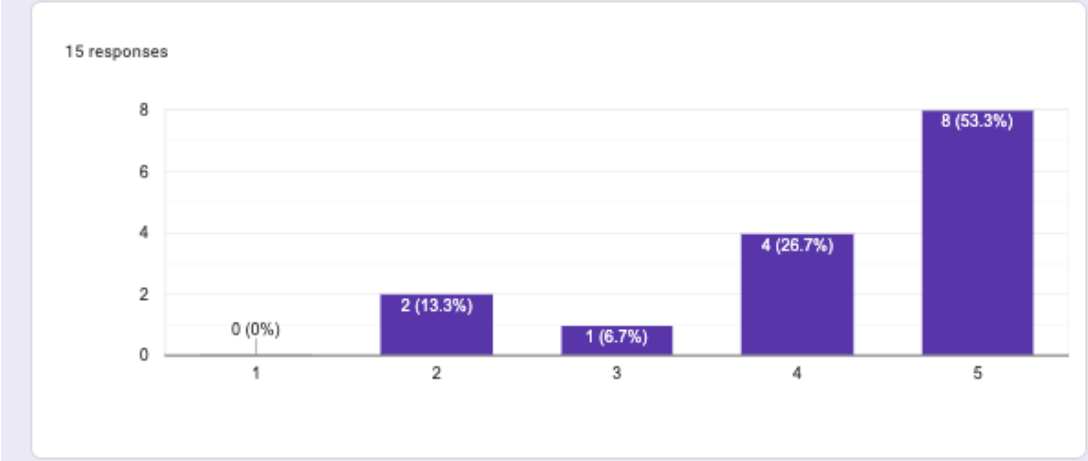


A.4.1 UEQ


15 responses
8
6
4
2
0
0 (0%)
0 (0%)
2 (13.3%)
5 (33.3%)
8 (53.3%)
1
2
3
4
5
15 responses
8
6
4
2
0
0 (0%)
1 (6.7%)
3 (20%)
7 (46.7%)
4 (26.7%)
1
2
3
4
5
15 responses
6
4
2
0
0 (0%)
1 (6.7%)
6 (40%)
3 (20%)
5 (33.3%)
1
2
3
4
5

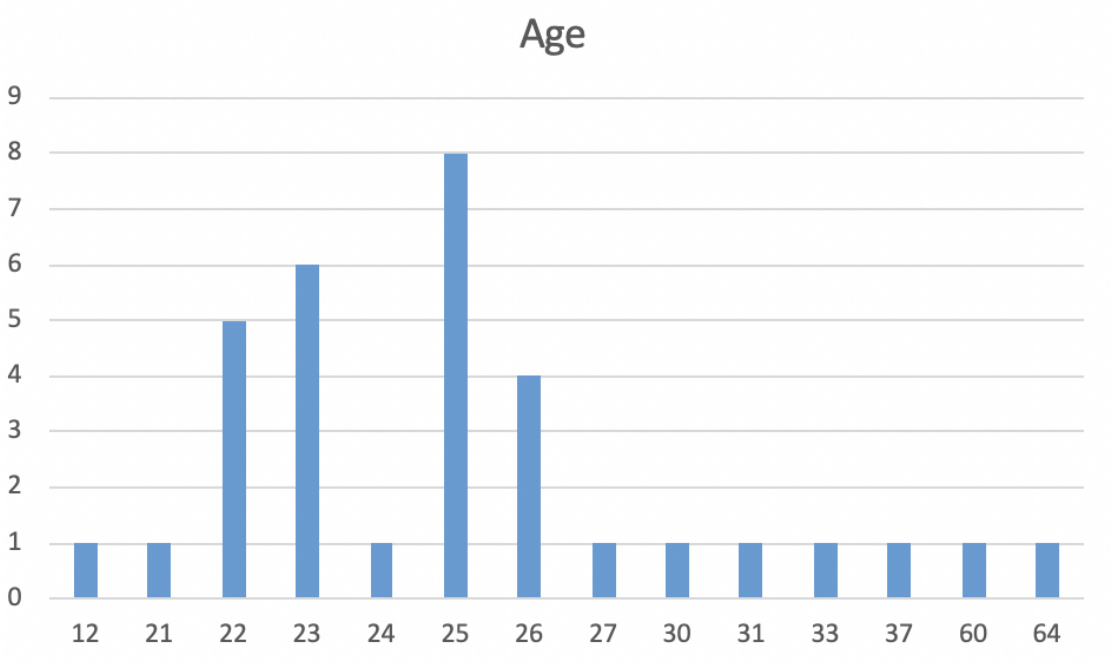

15 responses
6
4
2
0
0 (0%)
1 (6.7%)
2 (13.3%)
6 (40%)
6 (40%)
1
2
3
4
5

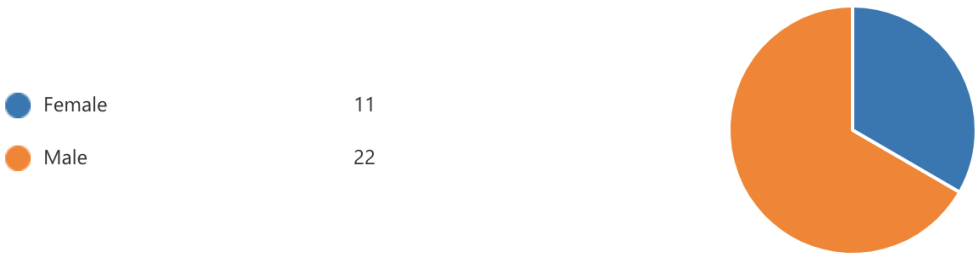

15 responses
8
6
4
2
0
0 (0%)
3 (20%)
1 (6.7%)
4 (26.7%)
7 (46.7%)
1
2
3
4
5

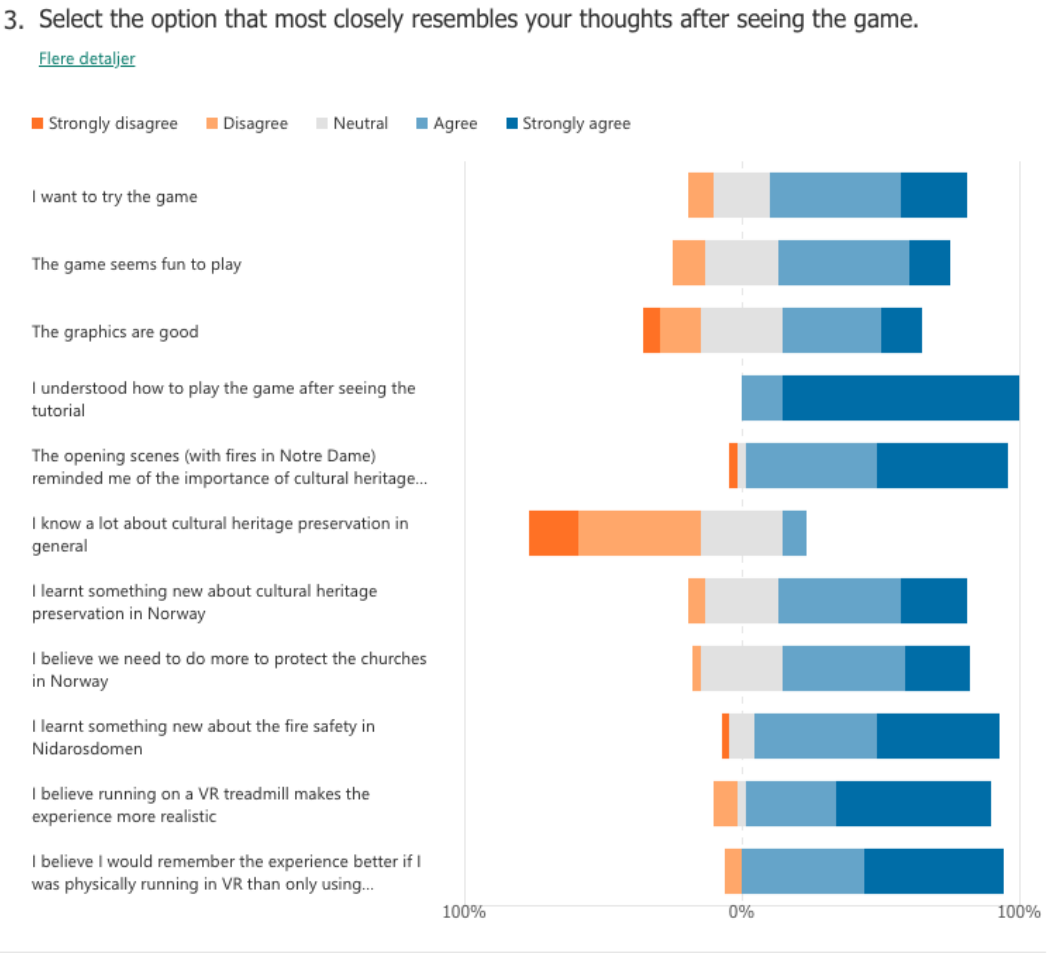

15 responses
8
6
4
2
0
0 (0%)
2 (13.3%)
1 (6.7%)
4 (26.7%)
8 (53.3%)
1
2
3
4
5


15 responses
10.0
7.5
5.0
2.5
0.0
0 (0%)
2 (13.3%)
2 (13.3%)
2 (13.3%)
9 (60%)
1
2
3
4
5
15 responses
10.0
7.5
5.0
2.5
0.0
2 (13.3%)
0 (0%)
2 (13.3%)
9 (60%)
2 (13.3%)
1
2
3
4
5

A.5 Fire application - Cultural Heritage






3. Select the option that most closely resembles your thoughts after seeing the game.
Flere detaljer
Strongly disagree
Disagree
Neutral
Agree
Strongly agree
I want to try the game
The game seems fun to play
The graphics are good
I understood how to play the game after seeing the tutorial
The opening scenes (with fires in Notre Dame) reminded me of the importance of cultural heritage...
I know a lot about cultural heritage preservation in general
I learnt something new about cultural heritage preservation in Norway
I believe we need to do more to protect the churches in Norway
I learnt something new about the fire safety in Nidarosdomen
I believe running on a VR treadmill makes the experience more realistic
I believe I would remember the experience better if I was physically running in VR than only using...
100%
0%
100%


Gjennomsnittlig vurdering 3.76

Muligens at bøttene med vann er større, men at du må være innen en viss radius fra dem før du kan plukke dem opp
Pilking up buckets from a distanse is a bit weird
The game seems okay for educational purposes, for example if the game was possible to play as part of a tour through Nidarosdomen. However, I would not spend money to play this game for pleasure at home. Maybe it there was a compelling storyline, with several levels and with differering gameplay between each level.
I didn't really see the connection between running around picking up buckets of water with all the issues described in the pre-game movie, eg. sprinkler systems and direct connection to the fire department
Run a bigger distance will make the game more stressful and maybe increase the point you are trying to make that our cultural heritage is not very protected
Lyden av vannstrålen blir nok oppfattet som skjærende i lengden. Mulig å gjøre lyden «fyldigere»? Hvis man skal åpne for mer spill-vinkling så ville det vært fint å ha et lite kart i et av hjørnene på skjermen som viser hvor brannen befinner seg i bygget. Da er det lettere å vite hvor man eventuelt skal løpe. Er det forresten nødvendig å starte det lille stykket unna bygget som gjør at man må løpe før «spillet starter»?

Better looking fires, more objectives than to only put out fire
Grafikk
I like the idea! But considering how much equipment is needed to play, the game feels a little too simple
Would be cool with a fire truck!
I think the game looks great, I wish i could try it. Think I would have learned a lot from it.
Give greater feedback on where you're actually hitting the flames. Could be some smoke-effect or other types of particles.
Additionnal features, other tools to deal with the fire
Mer forflytning rundt Nidarosdomen, behov for kontroll av at brannen er skikkelig slukket, kanskje noe lenger tidsperspektiv.
Obstacles when parts of the church collapses so that it becomes harder to finish the longer time you use.
Make the refilling of water a bit more immersive? Maybe include a pump or something to keep it closer to reality?

Appendix B

Interviews

B.1 Interview with VR expert

- Bugs/problems/improvements
- Immersion
- Outside issues
- Graphics/realism
- Informative, shocking
- Emotional effect/Motivational effect
- Metaphors
- Running

Morten: How was the experience? Did you have fun?

VR Expert: Yes, it was interesting. It was good to run a little bit (both chuckle)

Morten: What are your first thoughts after testing the application?

VR Expert: It's tricky, it's not very easy.Moving was a little hard. It's tricky to know how much you can reach with the water, especially when you're aiming towards the top of the cathedral. You're not sure whether you're actually touching it. And obviously,

you feel the pressure with the time. I struggled with my surroundings, I was getting tangled with the cable and hitting things around me. (in the real world) I didn't have a perception of what the distance was to things so I was basically pointing to hit the water buckets, but I was actually hitting the wall here (physically), so that was a bit of a distraction. But that's part of the immersion since I was fully into the game. I actually forgot what the left indicator was for, I thought that the red indicated that the person was going down and not that it indicates the health of the cathedral. I was just focused on the amount of water I had. That was hard to do, though it really makes you work for it. And for the second one, it was hard because I got stuck at one point. I couldn't really walk through.

Morten: Yes, I saw that, you got stuck between the bucket and the grave.

VR Expert: I'm not sure what happened there, but I lost a lot of time and with the effect of the water, I wasn't sure if it was hitting or not. And obviously in that one I performed even worse, but yes.

Morten: For the second one, the difficulty level was way too hard so that's on me.

VR Expert: The introduction is interesting, actually very informative. I really liked the view of the cathedral, it looks pretty nice. That part was good.

Morten: Thanks. So the aim of the experience is to raise awareness of the two main issues: Climate Change and Cultural Heritage Preservation. To what extent did the application achieve this?

VR Expert:It was a bit shocking to hear about the risk of the structures, I mean, I wasn't aware of the information the experience provides, but I assume that considering the value of Nidarosdomen, it's good to know they are looking after it. But it was shocking to hear how the other structures are, and that they are not that well protected; that makes you wonder.

Morten: So did you learn something new from the experience?

VR Expert: Yes, yes. I have been hearing about the one/two degrees in terms of water [sea level rise], but not so much about fires.[forest fire] So it's obviously worrying thinking that at the end of the century that can be a major problem.

Morten: In the beginning of the experience, you are shown a video corresponding to each issue. How effective were these videos for teaching about the issues?

VR Expert: I think they were good, they sort of provide context and examples of what can happen and you understand that it's not everywhere, but that illustrates the point well. In case of Notre Dame, obviously, it's simplified the difficulty, it doesn't matter if you have a proper response - even with that it's still going to be damaged and probably even lose the whole structure, regardless of how well prepared you were. And you realize that once it's gone, you can rebuild it, but it's not the same. For the other one[climate change], it has been less than a year since the fires in Australia and that tends to fade in memory, especially with what's going on now. But it [the experience] served as a reminder that it's there [climate change] and it's not going to go away.

Morten: The experience combines Climate Change, Cultural Heritage Preservation and Fire Safety in one application. How well do you think this works?

VR Expert: It's a gamified approach so obviously a firefighter won't have to go around picking up buckets. But as explained, the difficulty is very good. I think the bucket metaphor is very good to fight the fire. Obviously, here [in VR] you are safe, but you realize how difficult it is. So I think it's a very good way to understand the difficulty and challenges of not having the right conditions for protecting yourself against fire, especially around cultural heritage buildings.

Morten: Did the experience motivate you to act on either issue?

VR Expert: Yes, I think it was good, especially on the second one (about climate change) that you have these charts about different aspects and I think it's good to be shown what could be your contribution.[to combat climate change]

Morten: The game features a real location in Trondheim (Nidarosdomen, a cultural heritage) and it's on fire. How good was the realism and sense of presence?

VR Expert: I took it as a game,so as mentioned, I was immersed, but I didn't see it as very real. That could be seen by the fact that I could get very close to the fire. If that was a real fire, the heat wouldn't let you get withing 20-30 meters, but obviously you don't have that here so I took it as a game. However, I was fully into it in the sense that I have clarity that this is a gamified experience.

Morten: Do you think it affects you more emotionally being in a city you know such as Trondheim, compared to a generic city?

VR Expert: Yes, it does. Actually I was thinking that I didn't want to fail and I was a bit disappointed to let the church burn because I didn't want the cathedral to burn down.

Morten: To make the experience more immersive, you navigate the game using the Virtuix Omni. How well do you think this works? Did you feel immersed?

VR Expert: When you run in the beginning to the cathedral, you feel a bit frustrated because it takes a lot of effort to get there, but then you realize that if you were a firefighter running with hoses trying to get there, you're not just going to sprint, there is some level of difficulty moving around. So then you realize that this actually makes sense. So yes, I think in this case it works really well because it actually displays the same level of difficulty as if you were actually fighting fires.

Morten: What positive/negative aspects can you think of for using the Virtuix Omni for these types of applications?

VR Expert: If there is a point where you are supposed to run and you can't, that breaks the experience, but that's just a glitch/bug more than anything else. I think for the experience it's quite logical when there is a reason for not running the same speed as you normally would or move the same you would normally. So in this case, this is implicit there, some people might not necessarily see it immediately, but on reflection you can understand why. So for this particular case it makes a lot of sense.

Morten: What's the overall/general impression of the running part? Did it work well?

VR Expert: Yes, it worked well. I was focused more on the cathedral and was running around when I needed to and when I got there it was just a matter of finding the water and everything. It was very immersive.

Morten: What's your overall impression of the game? Would you recommend it?

VR Expert: I think it's a good prototype. As with anything, you can do adjustments, but for the description you made for what you wanted to achieve with it - I think it's a good one. I'm sure if more people are exposed, you can get more valuable feedback on

what to add, but as a start it's quite good. It's really immersive. I really like it and I think it is something that will be good to try [for other people].

Morten: What do you think can be improved?

VR Expert: I would say the biggest thing would be better with the water, in terms of where it is you're applying it, but I can't speak for the complexity of that. If this is the work of one person, it's very good. More realistic water can take a lot of effort and resources. It should be pointed out to anyone who uses it why there is no indication of time. When the game ends, you initally think "I didn't have a warning". You had in a way, with the indicator. You sort of expect something else, but in reality it is happening in the real world, when it burns, it's not going to give you a lot of leeway. I think it's a pretty good combination between components of "this is a game for you, so we give you this indicator" and "at the same time there are things we don't tell you. " So this is a game that is interesting, but might require some people to reflect on what happens so you actually understand what was going on.

Morten: Any other comments? **VR Expert**: I think it was good. Well done. I like that it sends the message you want to send.

Taking part in the research project

” Immersive Technologies for Learning and Training”

This is an inquiry about participation in a research project where the main purpose is to to explore the potentials and limitations of Immersive Technologies (virtual/mixed/augmented reality, VR/MR/AR) for learning and training in different areas, as a part of master student projects at Innovative Technologies for Learning (IMTEL) VR lab. To conduct this research, we will need to investigate the development and use of immersive technologies for learning and training in various contexts, including learning of language and mathematics, visualization of climate change, immersive exploration of historical manuscripts, workplace training and visualization of medical procedures. In this form we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project
To conduct this research, we will need to analyze the use immersive technologies for learning and training in various contexts, including learning of language and mathematics, visualization of climate change, immersive exploration of historical manuscripts, workplace training and visualization of medical procedures. The goal is to develop innovative learning methods and tools using immersive technologies.

Who is responsible for the research project?
NTNU, Department of Education and Lifelong learning is the institution responsible for the project.

Why are you being asked to participate?
You are asked to participate because you are a potential user of educational applications developed as a part of this project and have visited our lab/expressed interest in immersive technologies. Your feedback is important for develop innovative learning methods and tools.

What does participation involve for you?
You will be ask to test immersive applications for learning and training purposes and then give feedbacks in the form of questionnaires and interviews/group interviews.

Participation is voluntary
Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data
We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Any data that can be traced to individual participants will be kept confidential and anonymized before being used for research purposes. Parts of the sound recordings will be transcribed (written down) and stored electronically. All source data will be handled and stored in accordance with the existing regulations by NTNU as the responsible institution and only persons associated with the project (IMTEL VR lab research personnel and master students) will have access to them.

What will happen to your personal data at the end of the research project?
The project is scheduled to end 31.12.2020. All data will be anonymized at the end of the project, e.g. audio and video will be deleted when transcripts and analysis of data are completed, except for selected video and photo material to be used for research purpose. These and anonymized recordings from the inside of the virtual environments may be used for demonstrations in research context in such a way that no information will be linked to individuals. Scientific reports and presentations from this study might contain recordings from the VR/MR/AR sessions, questionnaire results, anonymized photos/videos from the sessions and anonymized citations from the interviews.

Your rights
So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?
We will process your personal data based on your consent.

Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?
If you have questions about the project, or want to exercise your rights, contact:

- Ekaterina Prasolova-Førland (Department of Education and Lifelong Learning, NTNU)
- phone: +47 99 44 08 61, email: ekaterip@ntnu.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Consent form

I have received and understood information about the project **Immersive Technologies for Learning and Training** and have been given the opportunity to ask questions. I hereby declare my consent that my data in relation to Immersive Technologies for Learning and Training may be stored, documented and used for research and educational purposes as described above. I give consent for my personal data to be processed until the end date of the project, approx. 31.12.2020

Jose Garcia, May 13th, 2020

(Signed by participant, date)

Bibliography

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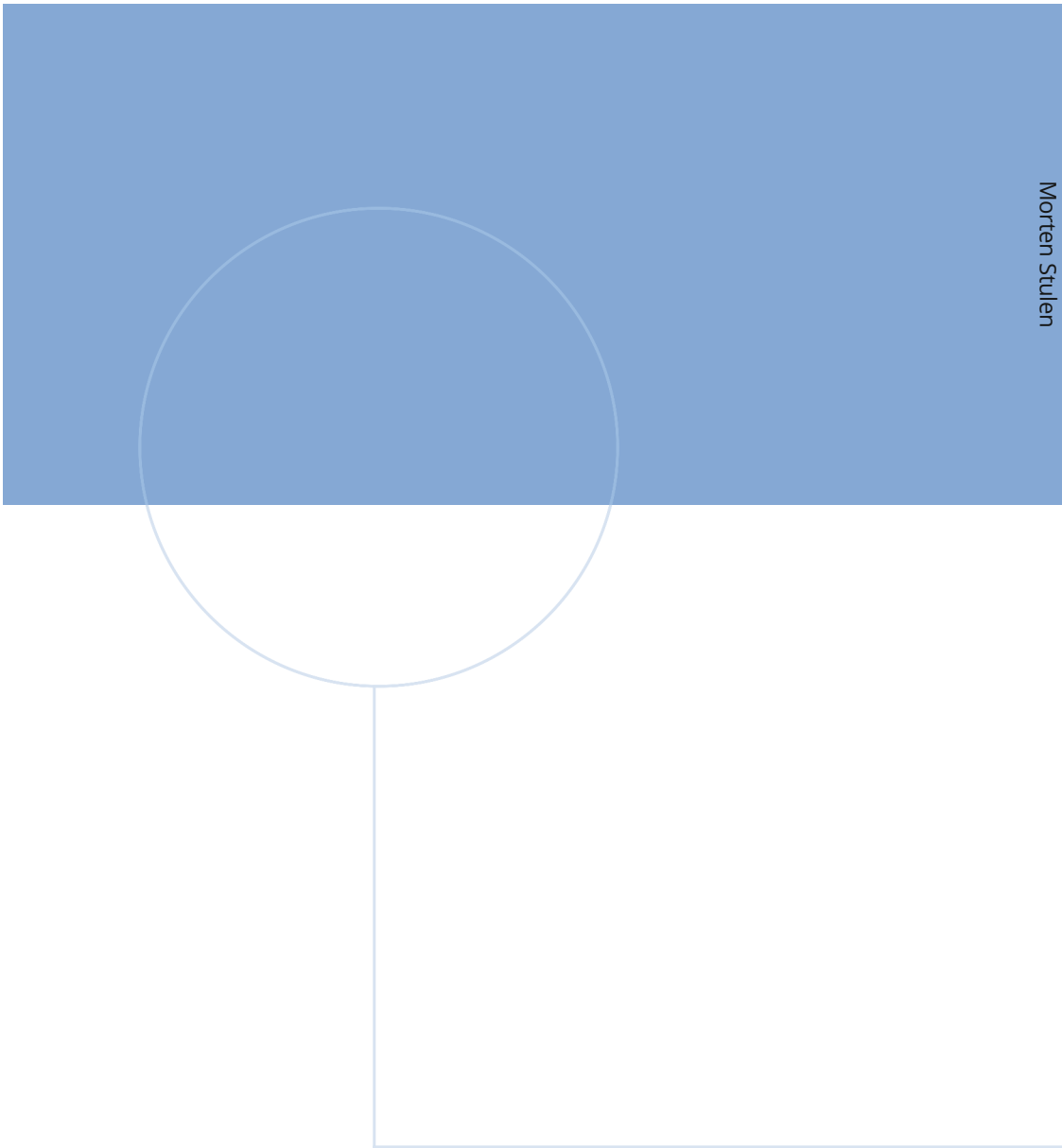

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