DriVR

A driving school simulator in VR

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jayway.

digitizing
ideas™

DriVR

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"VR works a thousand times better than 2D. The fact that you can look
around gives a complete new dimension to the simulator and looking
around your surroundings is just what driving is about."
- Test participant

June 1, 2018

LUND
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DriVR

Abstract

Many driving schools request cheap, safe alternatives to driving lessons. Some VR (Virtual Reality) car simulators already exist today, but they are either too expensive or not adapted to the Swedish traffic system. The purpose of this master thesis has been to investigate whether a virtual environment can be realistic enough for a driving school student to actually benefit from using it.

To answer the question, a user-centered design process has been executed during 20 weeks. The end product of this was a virtual environment, where users could use a car gaming rig and a VR headset to drive a car in VR.

One thesis before this project was that simulation sickness is a problem when using a VR simulator. The final result showed that this thesis to some extent is true, but the lack of physical feedback was the biggest problem. Other parts of the final result showed that a VR simulator gives a higher presence compared to classic car simulators where you drive with a 2D screen. Overall, you get more benefits than disadvantages from using a VR simulator. Therefore a driving school student can benefit from using a VR simulator.

Keywords: Virtual Reality, simulator, simulation sickness, user-centered design, virtual environment, VR simulator, driving school

Sammanfattning

Många körskolor efterfrågar billiga, säkra alternativ till körlektioner. Det finns redan VR (Virtual Reality) bilsimulatorer idag, men de är antingen för dyra eller inte anpassade för det svenska trafiksystemet. Syftet med detta examensarbete har varit att undersöka om en virtuell miljö kan kan vara realistisk nog för att en körskoleelev faktiskt ska kunna dra nytta av att använda den.

För att besvara frågeställningen har en användarcentrerad utvecklingsprocess genomförts under 20 veckors tid. Slutprodukten av detta blev en virtuell miljö, där användare med hjälp av en bilrigg samt ett VR headset kan köra bil i VR.

En tes inför projektet var att simulatorsjuka är ett problem vid användning av en VR simulator. Slutresultatet visade att denna tes till viss del stämde, men att avsaknad av fysisk feedback var det största problemet. Andra delar av slutresultatet visade att en VR simulator ger en högre övertygelse om att man befinner sig i den virtuella världen jämfört med klassiska bilsimulatorer där man kör med en 2D skärm. I helhelt får man ut fler fördelar än nackdelar av att använda en VR simulator och en körskoleelev kan därför dra nytta av att använda en VR simulator.

Nyckelord: Virtual Reality, simulator, simulatorsjuka, användarcentrerad design, virtual environment, VR-simulator, körskola

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CHAPTER 1

Introduction

1.1 Background

Virtual Reality (VR) has been around for a long time. In fact, many claim that it has been around since when the cave people drew paintings on the cave walls. Although this might seem somewhat far-fetched, it might be true. Virtual is defined as "being in essence or effect, but not in fact", while reality is defined as "the state or quality of being real. Something that exists independently of ideas concerning it. Something that constitutes a real or actual thing as distinguished from something that is merely apparent". Seeing how the cave paintings exceeded the physical experience of the cave people and then were used to create their own interpretations of the paintings, the cave people actually experienced a VR [1].

Today VR is much more advanced and in the past 15 years the development in the area has been huge. In 1960 Morton Heilig introduced the first Head Mounted Display (HMD) [2] which provided a basis for today's advanced hardware such as the Oculus Rift and HTC Vive. One of the big advantages of VR is that it can be used for simulation in training purpose. An example of where it is used is in the aviation industry where pilots need to practice complex situations before actually experiencing them in a real reality situation. Already in 1929 the "Link trainer" was developed by Edward Link. This was probably the first flight simulator created and was controlled by motors connected to the steering component and also a small motor to mimic vibrations and disturbance [2]. Today there exists plenty of flight simulators in VR with the use of a HMD. During a study at Mälardalens University two students drew the conclusion that flight simulators in VR with HMD is better for learning than traditional flight simulators without a HMD [3].

In the field of car driving simulators however, few options exist if you are to use a VR simulator with HMD. Many driving simulators exist but most of them are a built up simulation with multiple screens. According to the study at Mälardalen University, this does not work as well for learning. Some car driving simulators with HMD exists, but only a couple of them are built for a Swedish traffic environment.

During 2017, 275 200 Swedish driving students attended to driving-tests around the country. The fifth column in Figure 1.1, taken from www.trafikverket.se, indicates the percentile of passed tests. With this statistics, it is necessary to know what goes wrong. The driver does not calculate the risk during the driving, the driver missed to follow "the right-side rule" and driving to slow are some of the most common reasons of failure [4, 5]. The amount of time spent on learning to drive before the test might be another reason for failure. For this reason, the driving school student might not have been in some of the situations that often occurs while driving in traffic. The most common accident

in Sweden while driving outside of the city limit is a single vehicle accident. Since only one car is part of the accident, this indicates that the driver often does not have the risks in mind. Within the city limit the most common accident is a collision between two parties in a crossing [6].

TRAFIKVERKET

Antal Körprov B som genomförts på Trafikverket, perioden Januari - December 2017

Kontor*	Totalt Antal prov	Totalt Antal godkända prov	Totalt Antal underkända prov	Totalt Andel godkända prov	Kön Kvinna Antal prov	Kvinna Antal godkända prov	Kvinna Antal underkända prov	Kvinna Andel godkända prov	Man Antal prov	Man Antal godkända prov	Man Antal underkända prov	Man Andel godkända prov
Borås	7 662	3 964	3 698	51,74 %	3 140	1 683	1 457	53,60 %	4 522	2 281	2 241	50,44 %
Eskilstuna	8 840	4 545	4 295	51,41 %	3 767	1 993	1 774	52,91 %	5 073	2 552	2 521	50,31 %
Falun	9 607	4 564	5 043	47,51 %	3 746	1 973	1 773	52,67 %	5 861	2 591	3 270	44,21 %
Farsta	14 163	6 107	8 056	43,12 %	6 413	2 757	3 656	42,99 %	7 750	3 350	4 400	43,23 %
Gävle	8 268	3 646	4 622	44,10 %	3 130	1 565	1 565	50,00 %	5 138	2 081	3 057	40,50 %
Göteborg-Hisingen	23 372	11 221	12 151	48,01 %	10 232	5 011	5 221	48,97 %	13 140	6 210	6 930	47,26 %
Halmstad	6 418	3 010	3 408	46,90 %	2 566	1 254	1 312	48,87 %	3 852	1 756	2 096	45,59 %
Helsingborg	7 786	3 553	4 233	45,63 %	3 430	1 581	1 849	46,09 %	4 356	1 972	2 384	45,27 %
Jakobsberg	11 716	4 843	6 873	41,34 %	5 435	2 168	3 267	39,89 %	6 281	2 675	3 606	42,59 %
Jönköping	10 328	4 699	5 629	45,50 %	4 186	2 021	2 165	48,28 %	6 142	2 678	3 464	43,60 %
Kalmar	7 823	3 433	4 390	43,88 %	2 576	1 365	1 211	52,99 %	5 247	2 068	3 179	39,41 %
Karlskrona	7 526	4 056	3 470	53,89 %	2 747	1 596	1 151	58,10 %	4 779	2 460	2 319	51,48 %
Karlstad	8 868	4 905	3 963	55,31 %	3 439	2 105	1 334	61,21 %	5 429	2 800	2 629	51,57 %
Kristianstad	6 442	3 093	3 349	48,01 %	2 675	1 317	1 358	49,23 %	3 767	1 776	1 991	47,15 %
Linköping	14 160	6 111	8 049	43,16 %	5 840	2 654	3 186	45,45 %	8 320	3 457	4 863	41,55 %
Luleå	6 136	3 453	2 683	56,27 %	2 360	1 459	901	61,82 %	3 776	1 994	1 782	52,81 %
Malmö	17 153	7 534	9 619	43,92 %	7 734	3 405	4 329	44,03 %	9 419	4 129	5 290	43,84 %
MILITÄRA KONTORET	0	0	0	0,00 %	0	0	0	0,00 %	0	0	0	0,00 %
Skellefteå	2 101	1 101	1 000	52,40 %	773	485	288	62,74 %	1 328	616	712	46,39 %
Skövde	6 839	3 807	3 032	55,67 %	2 952	1 731	1 221	58,64 %	3 887	2 076	1 811	53,41 %
Sollentuna	13 596	5 579	8 017	41,03 %	6 060	2 431	3 629	40,12 %	7 536	3 148	4 388	41,77 %
Sundsvall	7 001	3 583	3 418	51,18 %	2 708	1 562	1 146	57,68 %	4 293	2 021	2 272	47,08 %
Södertälje	11 775	5 297	6 478	44,99 %	5 542	2 450	3 092	44,21 %	6 233	2 847	3 386	45,68 %
Umeå	4 117	2 191	1 926	53,22 %	1 700	997	703	58,65 %	2 417	1 194	1 223	49,40 %
Uppsala	8 829	3 803	5 026	43,07 %	3 848	1 668	2 180	43,35 %	4 981	2 135	2 846	42,86 %
Visby	2 044	954	1 090	46,67 %	863	425	438	49,25 %	1 181	529	652	44,79 %
Vänersborg	9 051	3 487	5 564	38,53 %	3 613	1 441	2 172	39,88 %	5 438	2 046	3 392	37,62 %
Västerås	10 909	5 642	5 267	51,72 %	4 600	2 441	2 159	53,07 %	6 309	3 201	3 108	50,74 %
Växjö	8 531	3 610	4 921	42,32 %	3 159	1 477	1 682	46,76 %	5 372	2 133	3 239	39,71 %
Örebro	8 781	4 179	4 602	47,59 %	3 692	1 847	1 845	50,03 %	5 089	2 332	2 757	45,82 %
Örnsköldsvik	2 455	1 408	1 047	57,35 %	917	590	327	64,34 %	1 538	818	720	53,19 %
Östersund	2 903	1 579	1 324	54,39 %	1 037	683	354	65,86 %	1 866	896	970	48,02 %
Totalsumma	**275 200**	**128 957**	**146 243**	**46,86 %**	**114 880**	**56 135**	**58 745**	**48,86 %**	**160 320**	**72 822**	**87 498**	**45,42 %**

Figure 1.1: Statistics of Swedish drive-tests during 2017. The fifth column ("Andel godkända prov") shows how many of the tests participants that passed. 46.86% passed the test during 2017.

1.2 Jayway

It was decided to develop this master thesis project at the Jayway Malmö office. Jayway is an IT consultant company with developers in all possible IT areas. They hope to be the leaders in VR projects in the future and took a great interest when this project idea was presented to them. The idea was something that they themselves had thought of developing so when the idea was presented to them it was immediately agreed upon doing this thesis at Jayway.

At Jayway there are a lot of developers with experience related to this project and good equipment and assistance to develop a high quality product.

1.3 Aim & Purpose

During this master thesis a driving simulator targeting Swedish driving schools will be developed. By testing the simulator on suitable test subjects, a wide spread of information will be collected. At the

end of the project, the main question to answer is:

Can a VR environment be realistic enough for a driving student to actually benefit from using it?
Additional sub questions to help answering the main question are:

- Can we make the user convinced that they actually are driving a car?

- Does the user feel that VR actually improves the presence or can a regular driving simulator perform the same level of presence?

- Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?

- Is there a reason for why this has not been implemented yet seeing how there is such a large interest in the project?

1.3.1 Limitations

The duration of this master thesis is set to 20 weeks. Therefore, the simulator can not include all situations that are practiced at driving schools. Chapter 5.1 presents statistics of what Swedish driving schools feel are the most important parts to learn while being instructed during driving lectures. These situations will be prioritized to include in the simulator.

1.4 Previous work

Some work has already been made in this area by other companies. Simulators closely related to this one has been developed for foreign country traffic environments. Also some projects developed specifically for Swedish traffic environment have been developed.

1.4.1 VRoom by Valtech

Two developers at Valtech developed a driving school simulator in VR named VRoom. The application was developed for an event called Valtech Day.
The purpose of their project was to create an option to practice driving without access to a car, provide the possibility to practice rare traffic situations and increase the students' confidence in traffic after using the simulator [7].
After reading about this project contact was made with the developers to get a better idea of what they had developed. The developers explained that VRoom is still a prototype and it does not have any alternative driving modes such as night drive yet. The prototype checks that the driver stops at red lights, drives within the speed limit and stops at crossings.
Users have experienced VRoom as realistic but some have also experienced simulation sickness. The developers pointed out the importance of the car physics in order to get this realistic experience.
The product is still a prototype and the developers have hopes to finish it later on. It differs from this project in the manner that this project intend to develop a complete product, not just a prototype.

1.4.2 VR techniques in driving education by STR

The Swedish National Association of Driving Schools (STR) is an organization for driving schools. They consist of over 600 driving school members which is 80% of all the driving schools in Sweden. They offer education for driving students and have over 2000 driving instructors in the organization [8].
In 2014 they developed a VR simulation program with a developer from Stunlock Studios. The simulation was meant to be used in future driving school education and the HMD used was an Oculus Rift. The motivation for the project was that many car accidents today are a result of lack of knowledge

or conscious wrong decisions. With simulated situations such as night driving, driving in rain, passing cars and phone usage while driving could be exercised and experienced.

After contact with STR their project was explained more in detail. The project was developed to be a "passive" simulation where the user sits in the passenger seat while the virtual driver uses his phone or while the virtual driver is drunk. The vice chairman of STR explained that with a "passive" simulation the users would not experience as much simulation sickness as they did in an "active" simulation. According to the developer from Stunlock Studios the users experienced the simulation to be very realistic and he himself though that the physics of the car were an importance aspect of getting the simulation realistic enough.

1.4.3   VectionVR

The Belgium company VectionVR offers a driving school built for VR [9]. Here the driver will do a series of driving exercises, see Figure 1.2 from www.vectionvr.com, to improve their driving skills. The simulator developed during this thesis will be similar to VectionVRs simulator. However, the primary target for this thesis are Swedish driving schools and the main focus will be of making the simulator as suitable as possible for them. Therefore the simulators will differ in that regard.

Figure 1.2: VectionVR with both driving exercises and driving in city area

1.4.4   City Car Driving

City car driving is developed for users to master the basics of driving in different conditions. The game offers a big variations of driving in many different driving areas, autodrome training, weather conditions and much more, illustrated in Figure 1.3 taken from www.citycardriving.com. It was released in 2007 with a 3D simulation of streets in Moscow. In 2010 the first English version of the game was released and is now spread world wide. Now it supports twelve different languages, US and European traffic rules, and it includes sudden dangerous situations to avoid. However, it does not have any Swedish traffic environment yet. It can be used with HMDs [10].

Figure 1.3: City Car Driving with autodrome training, driving in crossing and with different weather condition

1.4.5 VTI- Sim IV

The Swedish company VTI has developed several advanced driving simulators. Their latest product is the Sim IV which has large movement capabilities both on the X -axis and the Y -axis. In the Sim IV the user sits in a "room" with a tiltable car cabin (Figure 1.4 taken from www.vti.se) with three LED-displays for mirrors and nine projectors to display the surroundings [11].

Figure 1.4: The tiltable car cabin

CHAPTER 2

Theoretical background

Before starting a project it is important to understand the relevant theories and background related to it. Below some terms of high relevance for this project are presented in order to provide a better understanding of the rest of the process.

2.1   Virtual Reality

Many definitions of VR exist, which makes the term somewhat unclear and difficult to understand. A fairly easy definition was defined by merriam-webster.com where they explain that VR is "an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment" [12]. This definition is how most of us think of VR today, with a HMD and controllers connected to a computer, even though other definitions of VR does not even require a computer in order to achieve VR [2].

Today VR is mostly used in the entertainment industry. It has however also been deployed successfully in other industries such as military training and flight simulations and it is likely that education and professional training will be the next areas of industry to start using VR in a more serious way [13, p. 12].
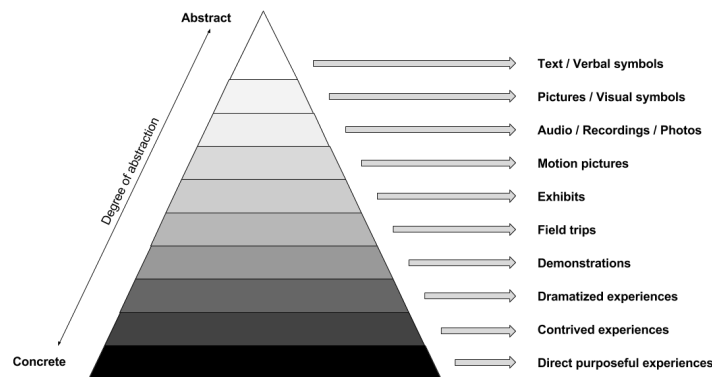
Figure 2.1: The Cone of Experience

Edgar Dale has presented a "Cone of Experience", visualized in Figure 2.1, which describes how learning experience is enhanced along with the usage of feedback to more of the users senses. The understanding and learning for the users increases the further down in the cone the application is placed [13, p. 12-13]. Thus, if a VR application is to achieve more understanding or learning, it needs

to go further down in Edgar Dale's Cone of Experience. For example, a plain text presented to a user would only reach the first layer of the Cone of Experience, while presenting the same information in a PowerPoint presentation with text and images would reach the second layer. In this case the learning experience would be greater for the user if the PowerPoint presentation would be used.

This project aims to reach at least the third deepest layer of The Cone of Experience. If this project would manage to simulate experiences that are dramatizing for the user for example, it would reach a high user learning experience since it would reach the third deepest layer.

2.2 User-Centered Design

In order to create a system for the users that is both usable and useful the User-Centered Design (UCD) process can be used. This process focuses on the users, the user-needs and the user-requirements. By using knowledge and techniques about usability the user satisfaction, accessibility, effectiveness, efficiency, human well-being and sustainability can be improved [14]. Usability is defined as the degree to which a system can achieve specified effectiveness-, efficiency- and satisfaction-goals in a specified use context for a specified user [15].

The UCD is built up by four activities that are iterated in loops, as illustrated in Figure 2.2. These activities are: **Observation**, **idea generation**, **prototyping** and **testing**[16, p. 221-222].
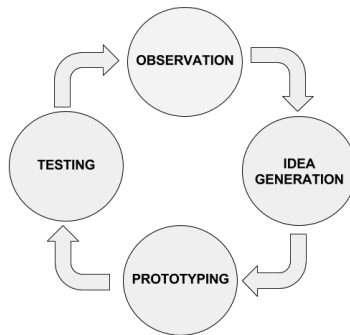
Figure 2.2: The iteration loop of a UCD process

Observation is about understanding the customer and potential users of the product [16, p. 222]. In the case of a VR- project this could for example include activities to collect data which will help developers to understand how to achieve presence and immersion for their target user-group.

Idea generation is done after the observation stage and is where potential solutions are created [16, p. 226].

Prototyping is the activity where prototypes are created. Without this stage there would be nothing to test for the users. In early stages of the process the prototypes might be only drawings while prototypes in later stages might be an almost completed product [16, p. 227].

Testing is the final activity of the UCD iteration loop. Testers representing the target user group are gathered to try out the prototypes in a way as similar to the real usage of the product as possible[16, p. 228]. In a VR- project this activity might in the first stages be testers looking at paper sketches and making comments. In a later stage the users might use the full VR equipment to interact with the full project.

2.3 Prototype

During this project a lot of prototypes will be created. Prototypes can be Low Fidelity (Lo-Fi) prototypes or High Fidelity (Hi-Fi) prototypes.

Lo-Fi prototypes in this project will refer to drawings and sketches of how something will be designed. These Lo-Fi prototypes will be the inspiration for the Hi-Fi prototypes.
Hi-Fi prototypes in this project will refer to a usable system that is not entirely completed. The final prototype from the development will be referred to as a product.

2.4 Presence

It is hard to define this phenomenon, because it is an inner psychological state. However, Jason Jerald defines it as following: "Presence, in short, is a sense of being there inside a space, even when physically located in a different location" [13, p. 46]. Presence can also be divided into two parts: physical presence and social presence. The authors' of the article "Physical and social presence in collaborative virtual environments: Exploring age and gender differences with respect to empathy", define physical presence as follows [17]:

1. A sense of physical space meaning the experience of physically "being there" in the virtual environment

2. Involvement or engagement as the ability to focus one's attention on the virtual environment and block out distracting cues from the surrounding physical environment

3. The perception of the virtual environment as coherent and believable

Jason Jeralds definition is similar to the first out of these three definitions.

To think that the you are communicating and being together with a person even though it is an avatar is called social presence. The social influence theory describes two aspect to why people experience social presence [17]:

1. Agency as the user's belief that the avatar is being controlled by a human in contrast to a computer

2. Communicative realism as the believability of the avatar's communicative behavior

So in short, social presence means that the users feels like he or she is communicating with a someone in the fictional environment.

2.5 Immersion

According Viktoriya Loboda and Ihor Katernyak immersion in a virtual learning environment is when complete social and cognitive presence is achieved by the learners [18].
In his book on p. 45, Jason Jerald describes immersion in more detail. He explains it as a combination of six parts to create stimuli onto the sensory receptors:

Extensiveness: How visuals and audio is presented to the user
Matching: The presentation of head motion and one's own body
Surroundness: Field of View (FOV)
Vividness: Resolution and lightning
Interactability: Capability to interact with objects in the world

Plot: The dynamic unfolding sequence of events.

Achieving immersion is one of the keys to a make a VR application believable.

2.6 Mapping

When building a product it is important to think about the mapping. The term comes from mathematics and describes the relationship between two set of things [16, p. 20]. This means that parts with a relation within a product should be placed in a way that feels natural for the user. One example could be lamps located in different parts of a room. The switch for each lamp should be placed so that it is clear which switch is controlling which lamp.

2.7 Affordance

Mapping is the relationship between objects, affordance is the relationship between an object and a person. The object provides opportunity and capability to interact with it to the person [16, p. 11] [19]. The user knows *how* to interact with an object if it is designed in the right way. If a chair does not afford sitting, the designer has not thought of affordance when designing it. Therefore, the concept of affordance is an important part of the designing process.

2.8 Vection

Vection is a well-known phenomenon that describes the creation of self-motion illusion in absence of physical movement[20] [13]. A classic example of proving this, is when a person is seated on a train and the train beside start moving. The person might at this point experience that he or she is on the train that is moving. This phenomenon is a factor that can cause simulation sickness.

2.9 Simulation Sickness

When VR is used with a HMD there is a great risk that a conflict will appear between what the user sees and what physical forces the body actually feels. Vision is our strongest sense and when a conflict due to physical motion appears we can experience a phenomenon called motion sickness or simulation sickness. Simulation sickness is the most common negative effect users experience while and after being exposed to VR. The most common symptoms are dizziness, general discomfort, nausea, headache and in the worst cases even vomiting [13, p. 163].

2.10 Feedback

Donald Norman [16, p. 23] and the authors of Interaction Design [21, p. 26] describe feedback as getting back information about what action has been done. With this a person knows what has been done and what the next step might be. Feedback is essential in every-day life. Playing the guitar without hearing music or pressing a button without anything happening would confuse the user. Without feedback we can not function.

CHAPTER 3

Technical background

In this project a list of technical instruments will be used. Some are hardware needed to produce the VR environment and some are software needed to build what will go into the environment. All of them are presented below to give the reader an understanding of what will be used to create the final product.

3.1 Oculus Rift

The main VR equipment that will be used is the Oculus Rift. Oculus Rift is developed and manufactured by Oculus VR, a division within Facebook inc. The decision to use Oculus Rift instead of another VR platform equipment was the access to hardware during development and the good reputation of the Oculus Rift.

Figure 3.1: The hardware components in a Oculus Rift VR platform

Figure 3.1, taken from www.elgiganten.se, shows the components of the Oculus Rift. The equipment is one headset, two controllers and two sensors.
The headset has a combined resolution of 2160 x 1200 pixels (1080 x 1200 pixels for each eye). The frame rate is 90Hz and the FOV is 110 degrees.
Seeing how this project will develop a car where the user interacts only with a steering wheel, gear box and pedals, these controllers will not be used in this project.
The sensors have accelerometer, gyroscope, magnetometer, constellation tracking camera with a tracking area of 5x5 feet if two sensors are used. [22].

3.2 Unity

Unity is a game engine platform used to develop games to a wide variety of platforms. Since Unity is the development platform for over two-thirds of the VR and Augmented Reality (AR) applications today there are plenty of accessible help to find on the web. Therefore, Unity seemed to be a good fit

for this project. It is also the only relevant platform the developers have experience in.

Unity comes with the Unity Asset Store where 3D models, scripts and more can be downloaded free or paid. Also, built-in physics engines and a wide range of tools makes Unity a powerful game engine platform [23].

3.3   Blender

Blender is a cross-platform 3D creation suite. The entire 3D pipeline of modeling, rigging, animation, simulation, rendering, compositing and motion tracking is supported [24]. It will be used in this project to create and modify 3D models.

3.4   3ds Max

Autodesk 3ds Max is a platform for creating 3D models, 3D animations etc. An integrated feature called Populate is a quick and easy way to create and animate humans. Humans created by Populate can stand still, sit down, walk around and much more [25].

3.5   Steering wheel & pedals

Logitech G920 Driving Force is the equipment that will be used for the car itself, it can be seen in Figure 3.2 below. This is fully equipped with a steering wheel with 900 degree turning, gas-, break- and gear pedals and a gearbox. The G920 Driving Force is primarily used for racing games to xBox and PC [26].

Figure 3.2: The Logitech G920 Driving Force, image taken from www.gamesmen.com.au

3.6   Playseat Evolution Alcantara

For a driver's seat the Playseat Evolution Alcantara will be used. This is a realistic car seat covered in black leather as shown in Figure 3.3, taken from www.mediamarkt.se.
This driver's seat is great for simulators and has support for attaching a steering wheel and mounting pedals. The seat allows adjustments so anyone can be comfortable using it [27]. Using a realistic car seat can very much help achieve higher sense of presence in VR.

Figure 3.3: Playseat Evolution Alcantara

CHAPTER 4

Method

This chapter will describe the work process of this project. The process was divided into three major phases, Research phase, Development phase and Evaluation phase. Each phase was divided into smaller parts, see Figure 4.1. Research, development and evaluation covered 20 weeks of work, were the Development phase was the longest.
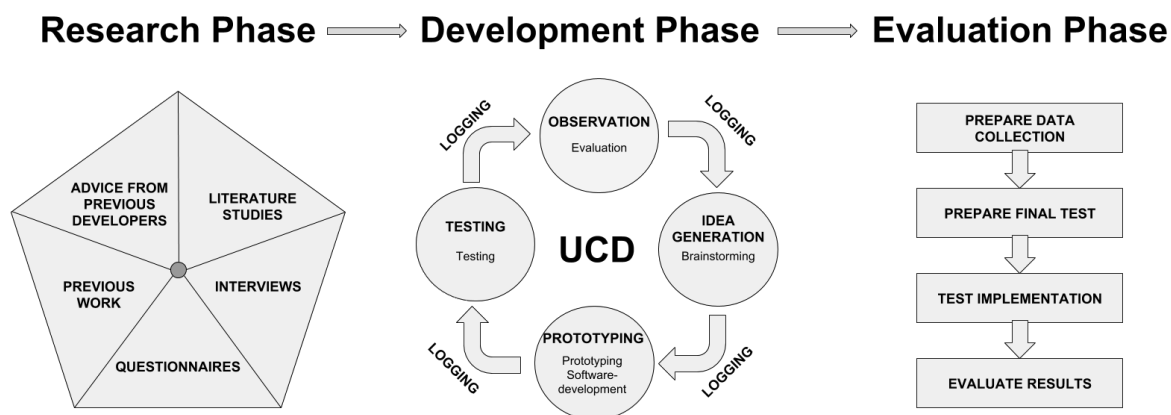
Figure 4.1: The process of the project

4.1 Research phase

The Research phase was performed during the first two weeks of the project. This phase gave a better understanding of the user needs, what had been done in this area earlier and what would be the difficulties in developing this project.

4.1.1 Literature studies

This part of the Research phase was about collecting as much useful information as possible. LUB-search and Libris were the two main search engines used to find academic articles. To find technical specifications Google was used. In Chapter 2 and Chapter 3, both the theoretical and technical information are presented. This information was used within the Development phase to ensure that the simulator became as realistic as possible.

4.1.2   Interviews

Interviews are a great way of collecting qualitative data and a great complement to the quantitative data of questionnaires. During the second week of this project a visit was held at a Swedish driving school. During this visit interviews were performed with a driving instructor as well as driving school students, both of which can be seen in Appendix A.

4.1.3   Questionnaires

As said above, questionnaires is a way to collect quantitative data. Therefore a questionnaire was sent out to Swedish driving schools. This gave a good overview for what was the most important features to implement in the simulator. The questions asked can be seen in Appendix B.1. Since this data shows what the driving schools and instructors want, it was good to collect quantitative data from the driving students as well. The questions asked can be seen in Appendix B.2.

4.1.4   Previous work

The previous work in the area presented in Section 1.4 was found using the presented search engines. What was mainly searched for was old useful master thesis as well as similar products on the market.

4.1.5   Advice from previous developers

Some of the developers of the previous work found were contacted to get a better idea of what they really had developed and to get advice on what parts were difficult and easy. The response we got from the developers is presented in Section 1.4.

4.2   Development phase

The development process followed the UCD-process which is further explained in detail in Section 2.2 and illustrated in Figure 2.2. This process contains four steps iterated until the end of a project, repeated in an agile manner. Each step of the process has been divided into activities to be performed at each iteration cycle. Between each of the steps of the UCD-process logging was performed to collect data and keep a solid audit trail of the development. The development process of this project is explained in more detail in Chapter 6 while the sections below describes each step of the process in general.

4.2.1   Observation

Observation was where a better understanding of the user needs and requirements were collected. This was usually done through questionnaires and interviews as well as observations from the tests. The data collected was stored in a folder for the current iteration cycle and used for the next step of the development process.

4.2.2   Idea generation

During brainstorming data from the Observation step was analyzed to make a proper decision regarding what should be implemented in the upcoming iteration cycle. Ideas were announced during open discussions and then given a priority.

4.2.3 Prototyping

Prototyping is where actual development took place and ideas from the brainstorming were implemented. At early project phases prototyping was done using pen and paper, resulting in a Lo-Fi prototype, while most iteration cycles included actual development in Unity, see Section 3.2, resulting in Hi-Fi prototypes.

4.2.4 Testing

In every development iteration, tests were performed to ensure that the development was going in the right direction. All the tests were divided in two parts: Driving and Questionnaires.

4.3 Evaluation phase

The final phase of the project was to evaluate the final product. This was done in a four step process consisting of the following steps: Prepare data collection, Prepare final test, Test implementation and Evaluate result. The Evaluation phase provided data to answer the sub questions and the main question of the project.

4.3.1 Prepare data collection

This step of the Evaluation decided what data should be collected from the tests, either from questionnaires or from observations, quotes, interviews etc. The aim of this step was to decide how the data should be collected. Each of the sub questions will be answered with data that is qualitative-subjective, qualitative-objective, quantitative-subjective and quantitative-objective. Qualitative data is data that is unique for a user, it could for example be quotes or answers in an interview. Quantitative data is data that can be used in statistics directly, for example yes or no questions and linear-scale questions. Subjective data is data that the user himself have entered, for example answers in a questionnaire. Objective data is data that the user have not entered himself, for example observations.

4.3.2 Prepare final test

This step was were all test materials were created and the final test implementation was decided. A test plan, briefing questionnaire, observation protocol and a debriefing questionnaire was created, all can be seen in Appendix C, D, E and F. After this step everything was ready and the final tests could start.

4.3.3 Test implementation

Testing was were all data was collected. The tests consisted of three steps, briefing, test execution and debriefing. Briefing and debriefing was made through questionnaires and test execution data was collected from observations during the tests. The aim was to test on 20 participants which was recommended as a good number of test participants from the supervisor of this project.

4.3.4 Evaluate result

Evaluating the results was mainly about interpreting the qualitative results and using these results together with the quantitative results to answer the sub questions. From this evaluation it was then possible to establish a conclusion for the project.

CHAPTER 5

Research Phase

As mentioned in Section 4.1, the Research phase consisted of five parts. The advice from previous developers was presented together with some of the previous work (see Sections 1.4.1 and 1.4.2). The outcome from the literature studies is presented in the Introduction chapter (see Section 1.1) as well as the Theoretical and Technical backgrounds (see Chapters 2 and 3). The interviews and questionnaires will be described here. During the Research phase data was collected from Swedish driving schools as well as Swedish driving school students. Both quantitative data from questionnaires as well as qualitative data from interviews was collected.

5.1 Driving schools

Questionnaires were sent out to 250 Swedish driving schools, and an interview was performed with a driving school tutor from Trafikpedagogerna in Lund AB. 45 of the driving schools answered the questionnaire and the results from this questionnaire is presented in Section 5.1.1 below. The result from the interview with a driving school tutor from Trafikpedagorerna in Lund AB is presented in Section 5.1.2.

5.1.1 Questionnaire

Question 1.
Are there any situations that the driving students most likely never experience during their time at the driving school?
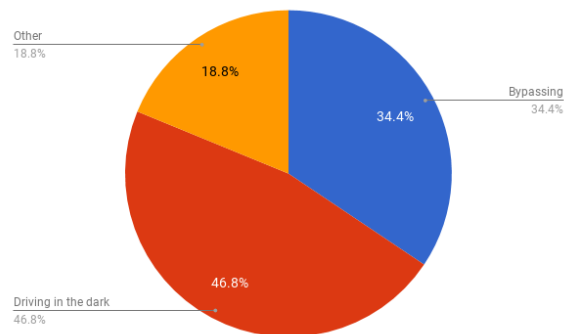
Figure 5.1: The most common situations driving students might not experience during driving at a driving school

Most driving schools answered either driving in the dark or bypassing other cars to be situations that the students' most likely never experience, as seen in Figure 5.1. All other answers were categorized as other.

Question 2.

Is there an interest from your driving school to use a VR driving simulator as a complement to the regular driving lessons?
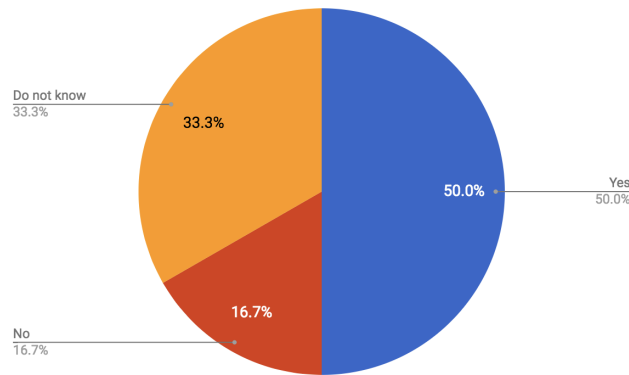
Figure 5.2: How many of the driving schools that have an interest to use VR as a complement to regular driving lessons.

Many of the driving schools were asked if *they* had an interest in having VR as a complement to regular driving lessons. It is clear to say that most of them want it or might consider it, as shown in Figure 5.2

Question 3.

Which of these situations do you think is the most important to include in the simulator?
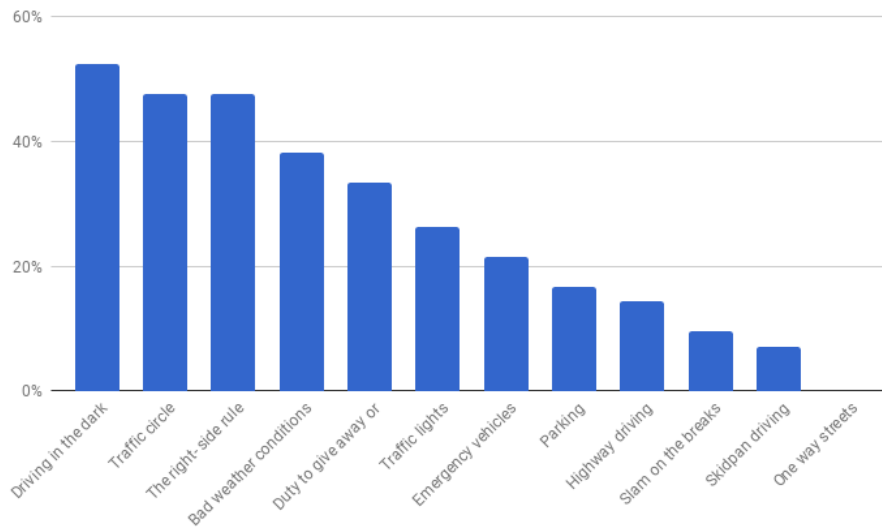
Figure 5.3: Answers from driving schools about which situations should be included in the simulator

There are many situations that should be included in a driving school simulator, but due to limitation in time, some had to prioritized. Figure 5.3 shows that some of the situations were more desired to be included.

5.1.2   Interview

The entire content of the full interview is too long to present here. Instead, some citations that are considered to be the most relevant have been selected and quoted below. The interview was performed in Swedish, so the presented quotes are presented with restrictions to the translations. Questions were asked about where most student experience difficulties and the instructor's thoughts on why this is. The full questions can be seen in Appendix A.

> *"The path towards the traffic circles is where it gets difficult, and it's because of the lack of awareness of your surroundings."*

> *"Since the students aren't aware of their surroundings, they feel that there is a lot happening at once."*

> *"To little practice is probably where it all starts."*

> *"It's very much about making the students understand why."*

> *"To see it for yourself, how you did, that wouldn't be a bad idea."*

> *"There are probably advantages from using it, I'm convinced it is. But the feeling of the car physics is where it differs. However, small things one can repeatably perform, that wouldn't be to bad."*

5.2   Driving school students

To get an idea of what driving students feel is the most important, interviews at Trafikpedagogerna in Lund AB was held, see Appendix A. At the same time, the nine students got to answer a questionnaire.

5.2.1   Questionnaire

The first question was about what kind of situations driving students might never have experienced while practice driving. Figure 5.4 shows what the asked student drivers had less experience in.

Question 1.

Which of these situations have you never experienced while practice driving?
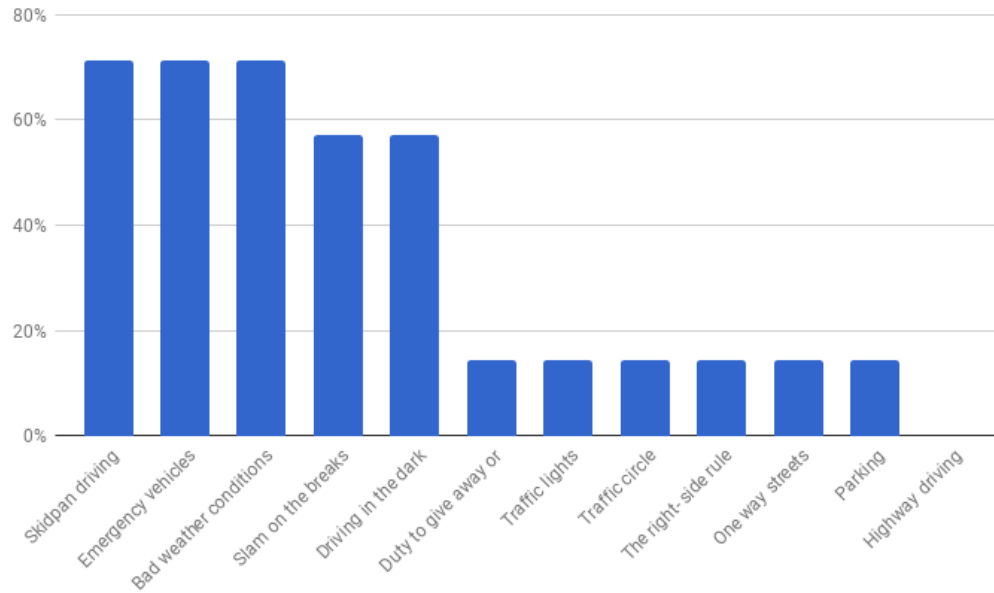
Figure 5.4: Answers from driving school students about what they never had experienced while practice driving

Question 2.

Which of these situations do you feel most insecure while driving in traffic?
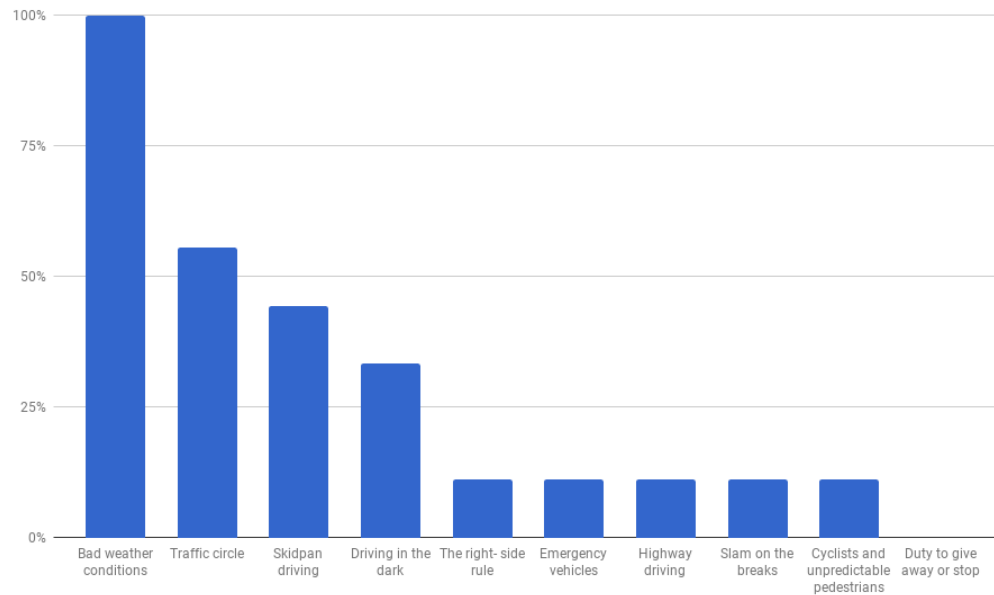
Figure 5.5: Insecure situations for the asked driver students

It is one thing to never have experienced a situation before and another to feel insecure with a situation. Therefore it is also necessary to know what makes student drivers insecure as Figure 5.5 shows. Another thing that was good to know was what the student drivers think is the most important to include in the simulator and that is what Figure 5.6 is showing.

Question 3.

Which of these situations do you think should be included in a VR simulator for practice driving?
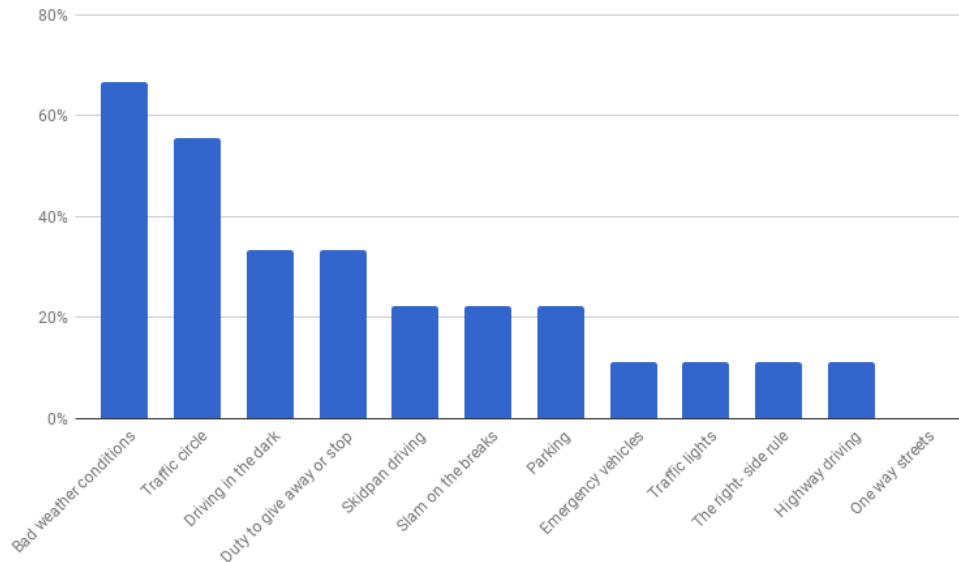
Figure 5.6: What the student drivers think is the most important to include in the VR simulator

Question 4.

Do you feel that a VR simulator for practice driving would be a good complement to the regular driving lessons?

The last question asked was if the students felt that a simulator would be a good complement for them. 100% of the answers were yes.

5.2.2   Interviews

All nine driving students were interviewed separately. The entire content of the full interview is too long to present here. Instead, some citations have been selected and quoted below. The interviews were performed in Swedish, so the presented quotes is presented with restrictions to the translations. Questions were asked about where the student experience difficulties. The full questions can be seen in Appendix A.

> *- "To keep focus on many different parts simultaneously, while driving at high speed"*

> *- "If many things happens at once or if I drive at high speed, estimations becomes more difficult"*

> *- "Which speed should I have while driving here? What distance do I need to keep to different kind of objects outside the car? The speed adaption is overall the hardest part."*

> *- "When emergency vehicles appears or I need to keep focus at many things at once, I easily become stressed."*

CHAPTER 6

The Development Phase

Following the Research phase was the Development phase. This was the longest phase of the project and follows the UCD- process described in Section 2.2. Each of the six iterations was planned to be two weeks long and is described below.

6.1 Iteration 1

In the first iteration it was decided to go from ideas (brainstorming and Lo-Fi prototype) to a complete road network (Hi-Fi prototype of the roads), before entering Iteration 2.

6.1.1 Observation

The Observation step within Iteration 1 was the first part of the Development phase. However, the data collected in this step was the data from the Research phase. The Observation step is explained in more detail in the Observation part from Section 4.2.1.

6.1.2 Idea generation

With a brainstorming session, ideas on how the world should be designed and what should be included in the simulator were presented based on our results from the Observation step. The ideas were discussed and prioritized and the most important results are presented in table 6.1.

Table 6.1: Result from the first brainstorming session

	Explanation
Driving in the dark	The result in the Observation step generated a good overview of what the driving schools as well as the driving school students thought were the most important features to include in the simulator. Therefore "driving in the dark" was the first traffic situation that was decided to be included in the simulator.
Traffic circle	Since this was thought as the second most important situation from the Observation step it was obvious to include traffic circles in the simulator.
The right-side rule	Driving in areas where a lot can happen at once makes drivers lose their awareness of the surroundings, see quotes from interviews in Section 5.1.
World structure	During the brainstorming session, five types of road networks were determined to be used in the simulator: City road, highway, country road, shopping area (for practice parking) and family neighborhood road (the right-side rule area). Within each of these areas different parts such as traffic circle, traffic lights, duty to stop and more were decided to be included.
Randomizing world	It was decided to have the world generated randomly so it is different every time the user drives. This idea was intended to be able to set different driving modes, e.g. practice traffic circles.

6.1.3   Prototyping

Prototyping was performed in two steps, one Lo-Fi prototyping step and one Hi-Fi prototyping step. During the Lo-Fi step, sketches of how each "Neighborhood" should be designed was made using pen and paper. This was a quick and easy way were the neighborhoods could be put together to see if the idea of a grid would actually work. Figure 6.1 shows how the world was meant to be built.
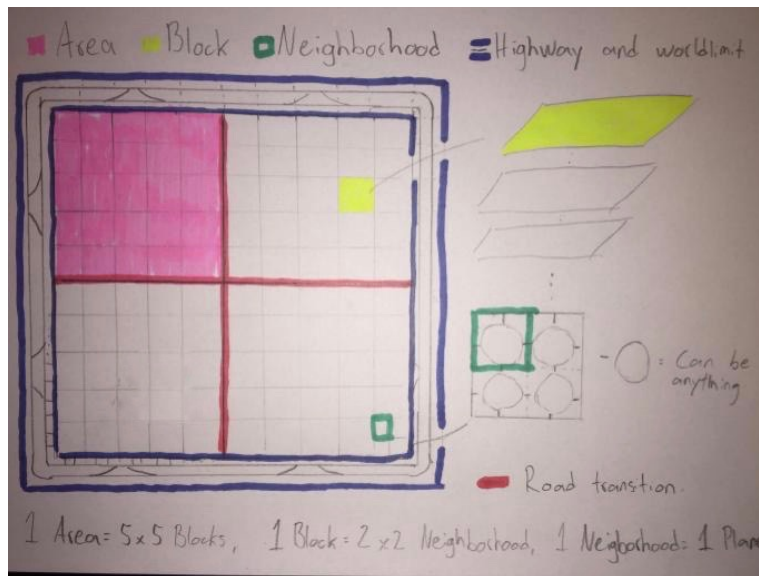
Figure 6.1: Lo-Fi sketch of how the world would be built up

The world consists of four "Areas", one city area, one shopping area, one family neighborhood area and one country area. Between each area a transition should be placed and around the world there will be a highway road. Each area consists of 5x5 blocks, where each block consists of 2x2 neighborhoods of 150m x 150m each, where each neighborhood has roads in and out at the same coordinates. Building the world this way would mean each block could actually be replaced by any other block and any block can be placed side by side to any other block, an example of this is shown in Figure 6.2. Also, if the world should be able to enter different simulation modes such as many traffic circles or many one way roads, this can be performed by letting each block be a parent with several child blocks where only the child block appropriate for the simulation mode is activated.
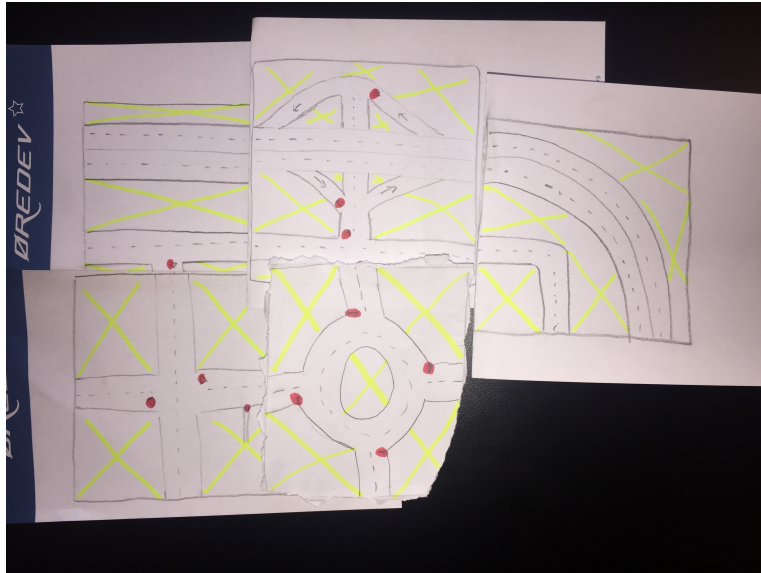
Figure 6.2: Lo-Fi sketches of neighborhoods put together to represent how a world would be built up

During Hi-Fi prototyping the purpose of dividing each block in four neighborhoods was questioned and it was decided that each block would instead be represented by only one 150m x 150m neighborhood. The idea generation step of this iteration (see Section 6.1.2) resulted in a list of neighborhoods which were prototyped in both Lo-Fi and later in Hi-Fi. Each of the neighborhood prototypes is showed below.

City area

For the city area two neighborhoods were prototyped. Figure 6.3 shows a neighborhood designed to contain many duty to give away or stop intersections. Figure 6.4 shows a very basic city neighborhood with one traffic light intersection.
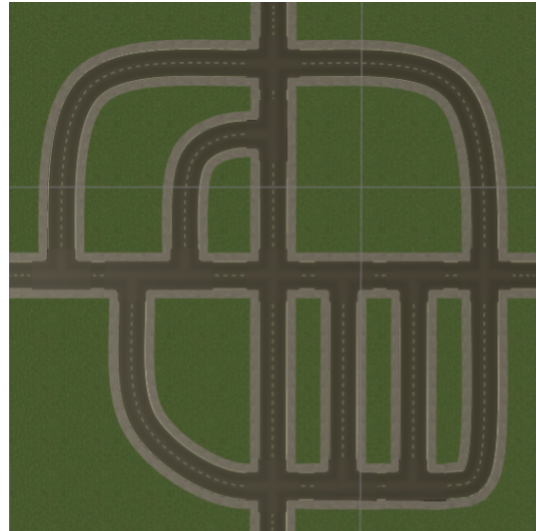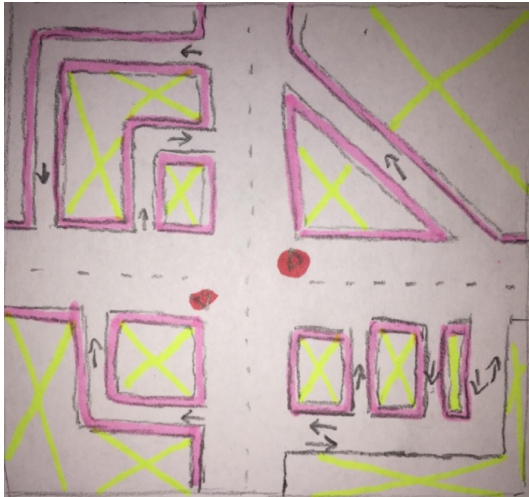
Figure 6.3: Lo-Fi and Hi-Fi prototype of city neighborhood
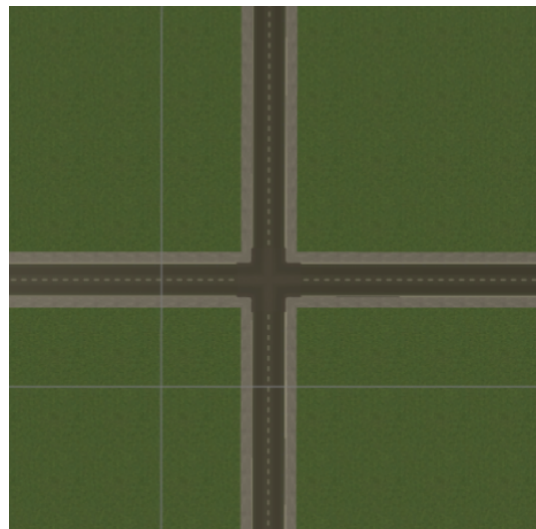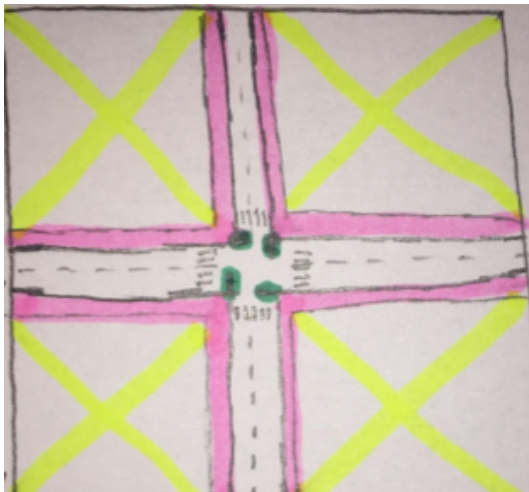
Figure 6.4: Lo-Fi and Hi-Fi prototype of city neighborhood

Family neighborhood area
This area is considered to simulate an area where the right-side rule is applied. As seen in Figure 6.5 the Lo-Fi and Hi-Fi prototypes differ slightly. The placement of the traffic circle did not feel realistic and was therefore replaced.
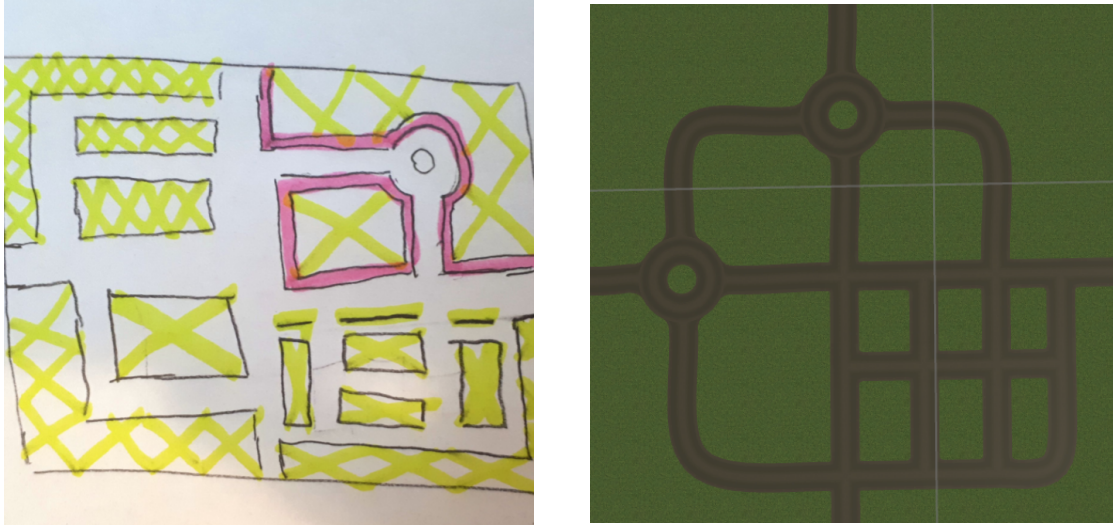
Figure 6.5: Lo-Fi and Hi-Fi prototype of family neighborhood

Shopping area
The shopping area was designed to be an area with many parking areas and traffic circles, as illustrated in Figure 6.6.
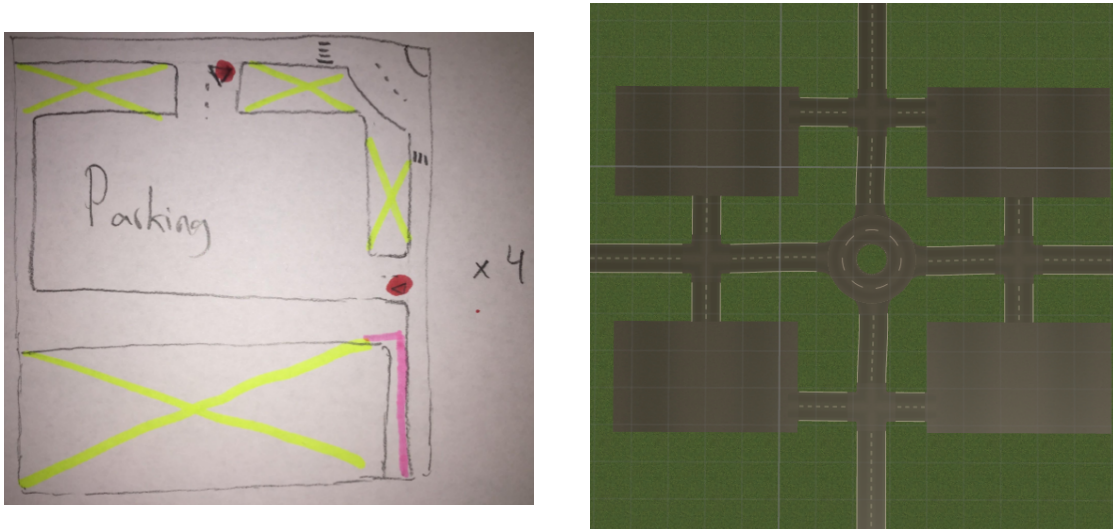
Figure 6.6: Lo-Fi and Hi-Fi prototype of shopping neighborhood

Country road area

The country road area consists of wider roads than in the other areas, a width of 14m instead of 8m. A two lane traffic circle was prototyped as illustrated in Figure 6.7 and one regular crossing as illustrated in Figure 6.8.
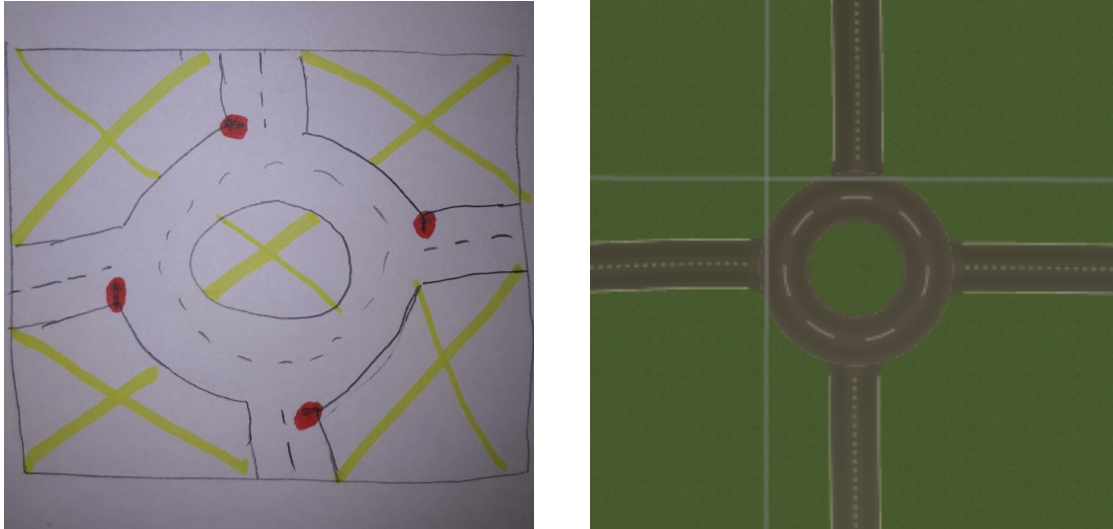
Figure 6.7: Lo-Fi and Hi-Fi prototype of country neighborhood
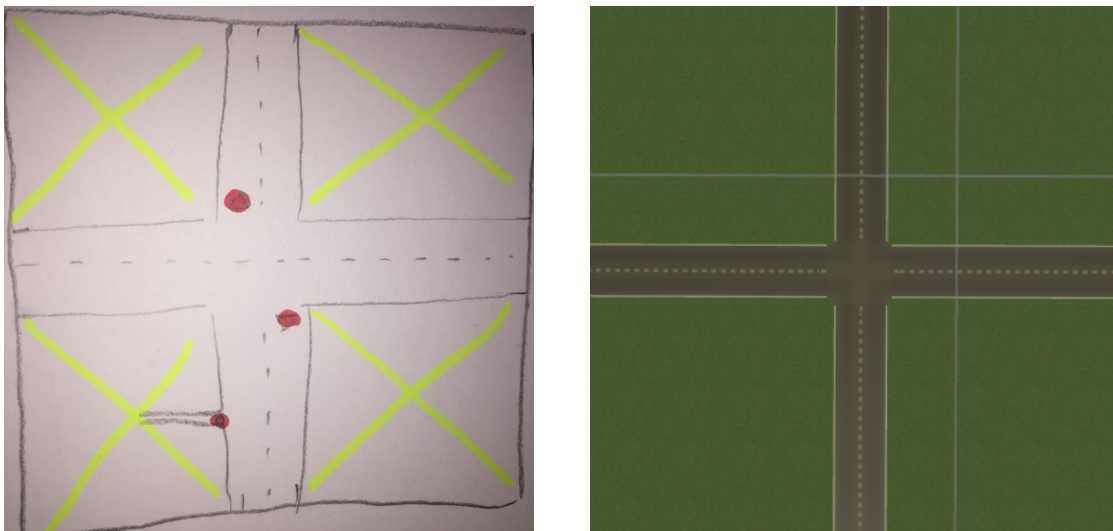
Figure 6.8: Lo-Fi and Hi-Fi prototype of country neighborhood

Highway

For the highway three prototypes were created. When Hi-Fi prototypes were created it became obvious that the highway exit and entrance were too steep and short. Therefore that block was instead created as a 750m x 150m block when created in Hi-Fi, as illustrated in Figure 6.9. To make it possible for the user to enter both directions of the highway the highway needed to be raised six meters above the ground.

During Hi-Fi prototyping it was also discovered that a highway part next to the transition parts of the world had been forgotten in the Lo-Fi prototyping. Instead this was only created in Hi-Fi and is illustrated in Figure 6.10. Figure 6.11 shows the design of the highway turns.
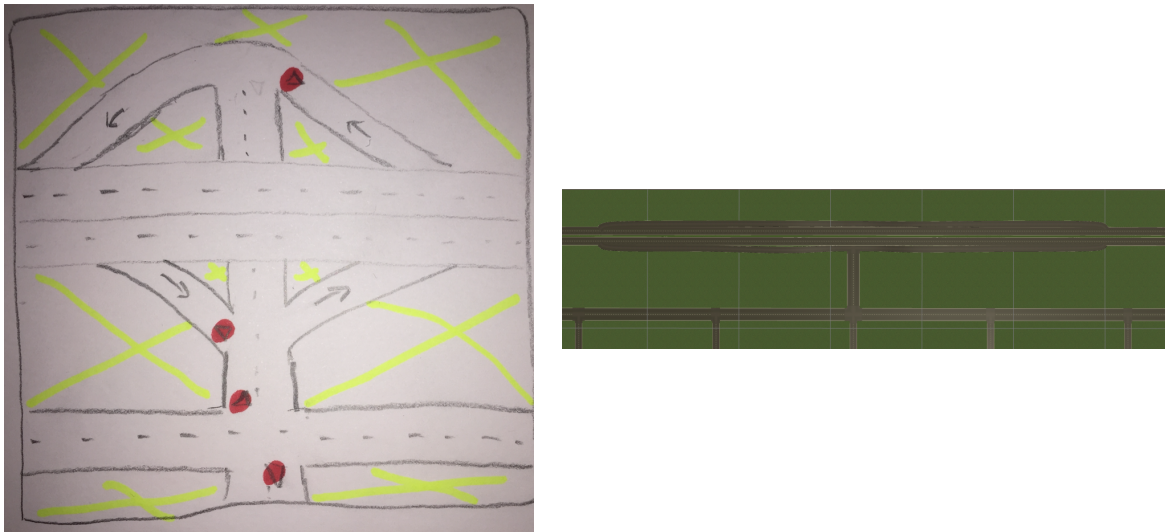
Figure 6.9: Lo-Fi and Hi-Fi prototype of highway block
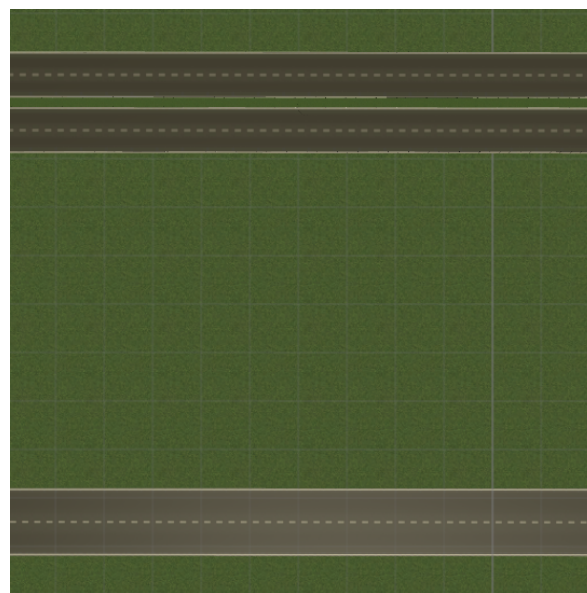
Figure 6.10: Hi-Fi prototype of straight part of highway
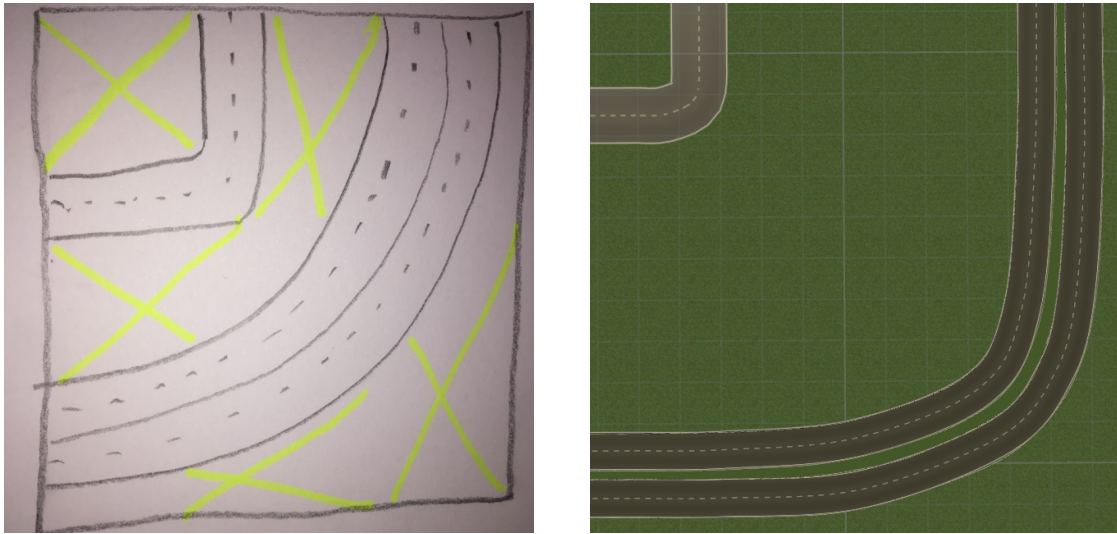
Figure 6.11: Lo-Fi and Hi-Fi prototype of highway block

Transitions

Between the areas transitions are placed. Since areas *might* have different road width, transition blocks with 8m-8m (e.g. city area to shopping area) and 8m-14m (e.g. city to country road area) needed to be placed between each area. To not have to many ways between the areas, some turning points are build in the transitions, see Figure 6.12 and Figure 6.13.

Figure 6.12: Lo-Fi and Hi-Fi prototype of transition from 8m roads to 8m roads

Figure 6.13: Lo-Fi and Hi-Fi prototype of transition from 8m roads to 14m roads

Complete world

Putting together the Hi-Fi blocks presented earlier, an entire world could be created. This is the world where the tests were performed and is visualized below in Figure 6.14.
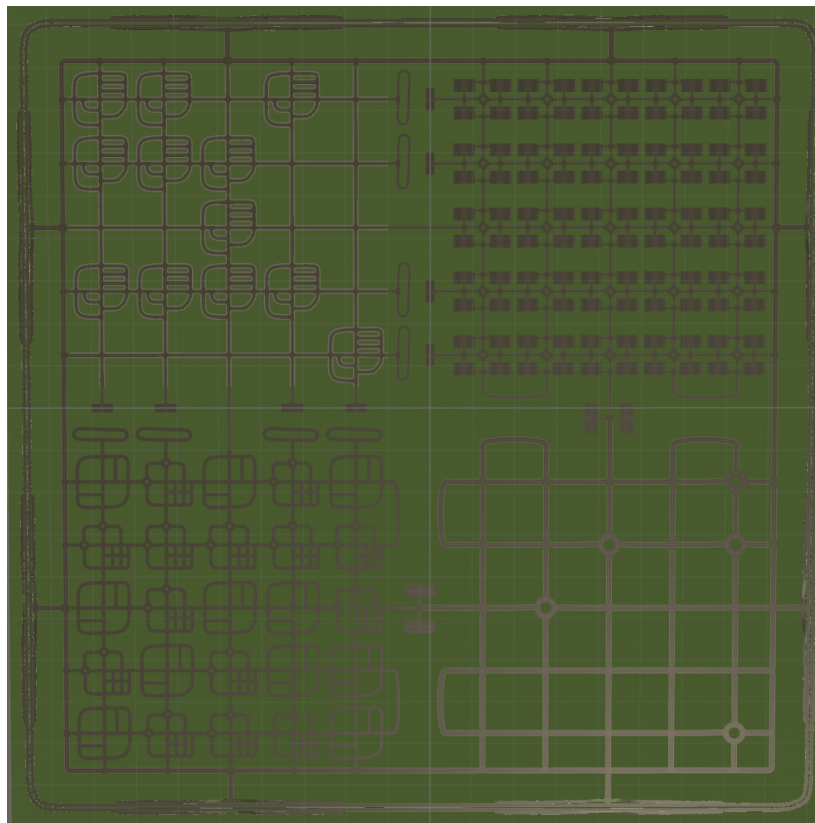
Figure 6.14: The Hi-Fi prototype of the entire world put together

6.1.4 Testing

This first test had six participants and the main goal was to determine if the size of the environment was realistic.

The tests were designed so that one developer was giving directions to where the tester should drive, resulting in the tester trying out all different road types. The tester controlled the car with the keyboard, see Figure 6.15, in hope that this would lower the risk of simulation sickness.

Figure 6.15: The setup for the first tests

After the test each participant was asked to fill out a form about their experience from the simulator. The result from the form is presented below. Figure 6.16 - 6.18 shows the results of the questions asked.

Question 1.
Did you experience the roads to be of a realistic size?
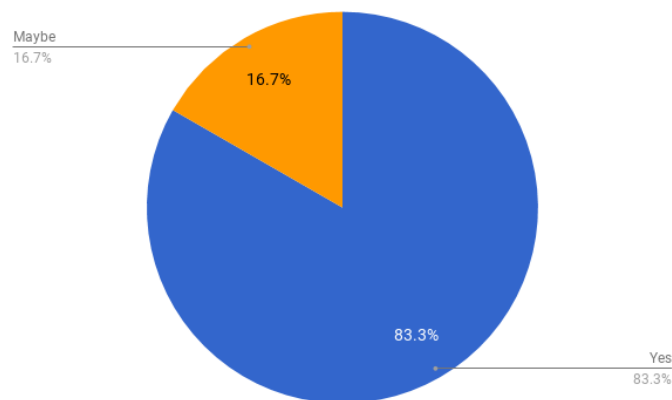
Figure 6.16: What the test participants thought about the road size during the first tests

Question 2.
Did you experience the road network to be realistically built?

Figure 6.17: How the experience about the road network was after Iteration 1

Question 3.
Did you experience any simulation sickness or other discomfort from performing this test?
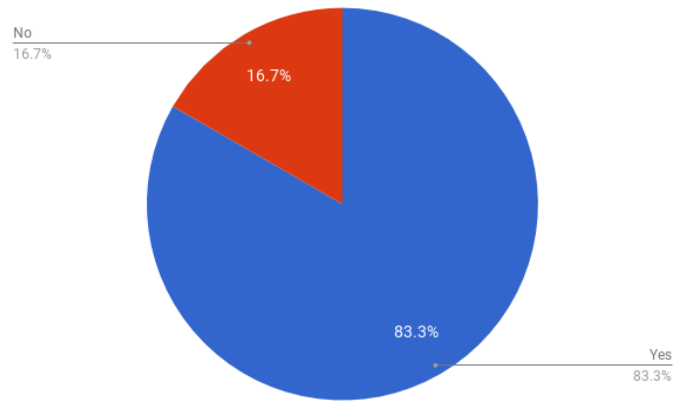
Figure 6.18: Simulation sickness during the first tests

The state of the simulator at this stage was considered to poor to be used for practice driving. With this in mind, the effect of simulation sickness was high. Five of the testers felt some discomfort and one of the participants had to abort the test.

All the testers gave input on what could be included to make the simulator more realistic and with this hopefully lower the effect of simulation sickness.

Quotes:

> - "The field of view is small, which makes me turn my head a lot. However, this might be good for the users to practice their awareness"

> - "The physics of the car needs to be better"

> - "To much turns"

> - "Add many things so the world feels more realistic"

6.2 Iteration 2

During the second iteration the virtual car was connected to the steering wheel and pedals, the virtual environment was rebuilt and the first traffic objects was created. The iteration was two weeks long.

6.2.1 Observation

From the user-test step of Iteration 1 valuable data was collected to get a better understanding of the user needs. From the tests it became clear that the car in its current state felt unrealistic and that simulation sickness was a big issue. Another issue was that the world did not feel realistic due to no surrounding environment, which was very expected.

6.2.2 Idea generation

After evaluating the test results a brainstorming session was issued where decisions for the new iteration were made. These are presented in the table below.

Table 6.2: Result from the second brainstorming session

	Explanation
Rebuild road network	The tests showed that a lot of users experienced simulation sickness. A decision was that one step to reduce simulation sickness is to have a lot less turns in the world. It was therefore decided to throw away the idea of a grid road network. This is mainly because the grid idea made it difficult to do modifications to the world, which often needed to be done. Also, the size of each grid box required the world to have a lot of turns.
Improve car physics	The users complained a lot about the physics of the car. The car skidded in almost every turn and turning was way to sensitive. This is why a decision was made to modify the CarController script to make car movements more realistic.
Integrate the simulator to the Logitech system (see Section 3.5)	By driving the car with an actual steering wheel and pedals the user will feel more convinced that they are actually driving the car both the immersion and presence will be improved. Also, with a steering wheel the turns will no longer be only either a full left turn or full right turn and turn sensitivity will be improved. Both the factors of presence and turn sensitivity is something that expected to result in less simulation sickness.
Create road signs	It was decided that the environment should start being built and that the first thing that should be built are Swedish road signs. The hopes were that this would improve the feeling of a realistic road network.

6.2.3 Prototyping

From the Idea generation step the only thing that needed Lo-Fi prototyping before actual development was the new road network. Car physics were modified by modifying scripts and the same goes for the integration of the Logitech system. Road signs were created in Hi-Fi directly after watching Swedish road signs from Google Maps street view.

Road Network
The new road network was decided to not be built up by several grid boxes to build up a grid world since this only caused problems. It was also decided that the highway should now only have entrances and exit on one side of the road, causing it not to have to be raised above the ground to reach the other side of the road. This was because many users experienced the peak of their simulation sickness when quick height differences appeared. The resulting Lo-Fi and Hi-Fi prototypes are presented in Figure 6.19 below.
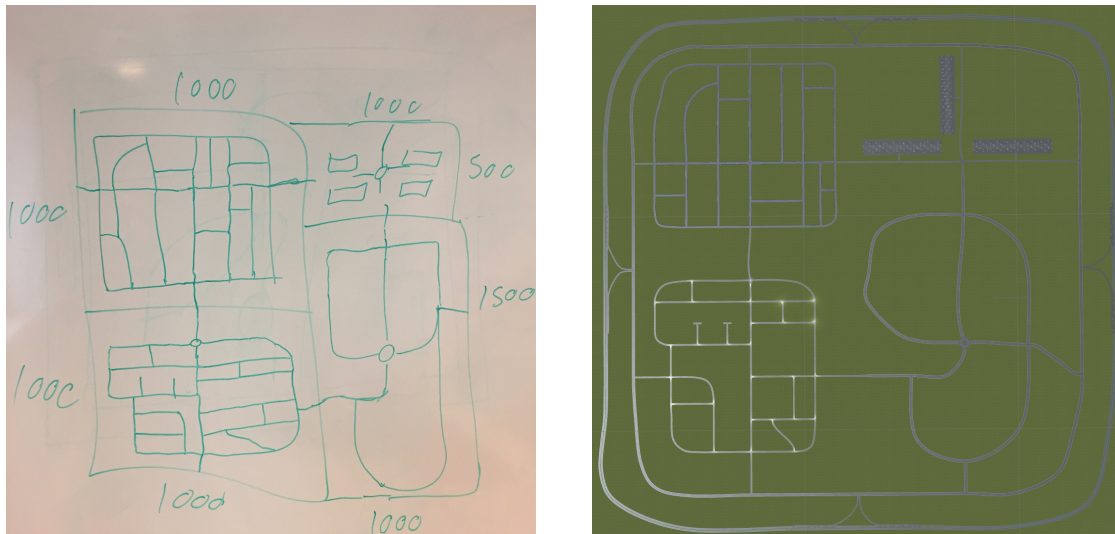
Figure 6.19: Lo-Fi and Hi-Fi prototype of the new road network

As can be seen in Figure 6.19 the world still consisted of the areas "City Area", "Family Neighborhood Area", "Shopping Area", "Country Road Area" and "Highway". The need for special transitions was no longer necessary. It was also decided to only have three parking spaces in the shopping area instead of four because it made the change of road width to country roads easier. At the parking several cars of the downloaded car prefab were placed to act as parked cars.

Road Signs
Road signs were first created in a separate project and later exported as prefabs to the main project. They were all created in Unity using a cylinder game object and a plane with the material being a png image usually collected from Transportstyrelsen [28] but sometimes created from scratch. The most common road signs were first created after using Google Maps street view in neighborhoods similar to those in the prototype, and more and more were created as their need was discovered. The current road signs can be seen in Figure 6.20.
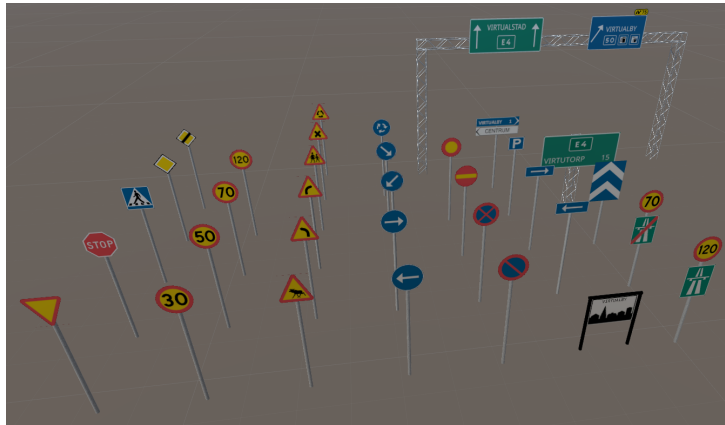
Figure 6.20: The road signs created in Unity

.

The measurements for the road signs were also mainly used from the website of Transportstyrelsen but some were estimated from comparing them to other objects in Google Maps street view.

Car

The car now has rear view mirrors and a modified script to make the car less sensitive for turns and also skid less. The script has also been connected to make the steering wheel turn the same amount of degrees as the user turns the Logitech steering wheel. The same goes for the speed pointer and rpm pointer which now show the actual speed and rpm. It is also possible to switch between full light strength and half light strength. The current car can be seen in Figure 6.21 below.

Figure 6.21: The current look of the car interior

.

As can be seen in the image, there has also been road signs placed on the streets as well as traffic lights. Also, clouds and a day-night system has been added.

6.2.4   Testing

> - *"Great potential. Possibility to be a good compliment for practising before taking*
> *your driver license"*

During the second Test step seven users participated, all co-workers at Jayway. Since the purpose of this test was to determine if the car felt realistic, the test subjects could be anyone with a driving license. In comparison to the first Test step when a test leader told the tester where to drive, this test was more open and the testers drove around in the virtual environment however they pleased.

Figure 6.22: The setup for the second tests
.

Just like the first test, the testers answered a questionnaire. The same questions were asked, to be able to see progress during the whole project, the answers are shown in Figure 6.23 - 6.25.

Question 1.

Did you experience the roads to be of a realistic size?
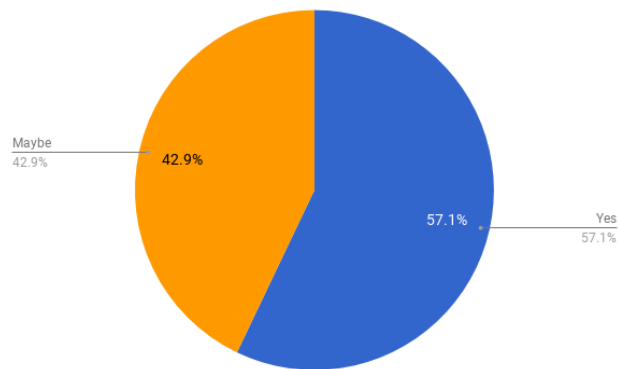
Figure 6.23: The tests during Iteration 2 shows that the test participants thought the road size was good

Question 2.

Did you experience the road network to be realistically built?
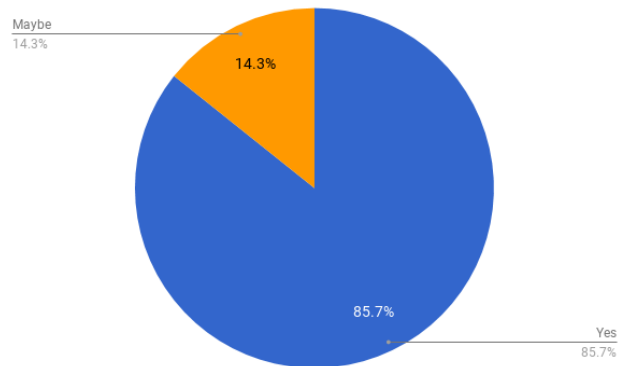
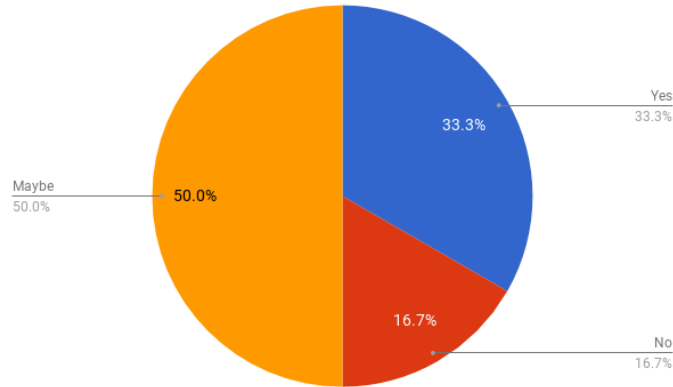Figure 6.24: The new road network was much more realistic than it was after Iteration 1

Question 3.

**Did you experience any simulation sickness or other discomfort from performing this test?**
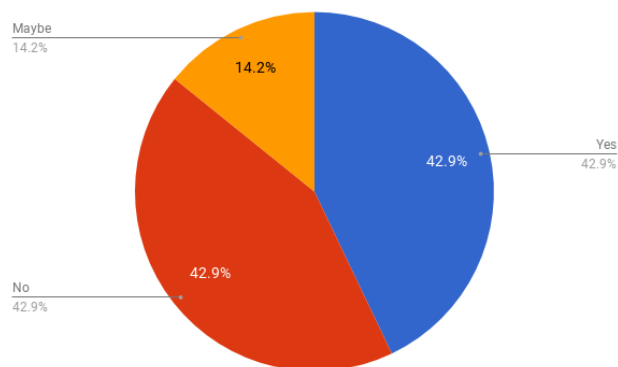
Figure 6.25: Simulation sickness during the second tests

Issues

- The ratio between camera and car was wrong, which made it feel like the car was tilting.

- Some areas in the world were lagging.

- The car stopped much faster than a real car when hitting the breaks.

- The drivers placement in the car could be improved.

- Simulation sickness still a problem.

- The turns and X crossings are to sharp

Suggestions

- Add more content to make the experience feel more alive.

- Make it feel more like your are sitting inside the car, by fixing the camera settings.

6.3   Iteration 3

This iteration handled a lot of optimization. This is something that was fairly new for the developers and a lot of new knowledge needed to be learned.

6.3.1   Observation

The previous iteration had some improvements in the biggest issue from Iteration 1, simulation sickness. However, during the tests of Iteration 2 many users experienced their positioning in the car to be a bit off, the experience was not smooth due to lag and turns were to sharp. All these factors resulted in a lot of users still experiencing simulation sickness. It became clear that the car positioning needed to be fixed, lagging needed to be removed and surroundings needed to be included to make the experience more realistic.

6.3.2   Idea generation

Just like the previous iterations there was a brainstorming session after the observation of the test results. Many ideas for improvements were suggested and the highest prioritized improvements are listed below.

Table 6.3: Result from the third brainstorming session

	Explanation
Create buildings, environment & surroundings	The users asked for more content in the world to make it feel more alive. There was a belief that by doing this the immersion and presence would be improved which might result in less simulation sickness. It was therefore decided that buildings and environment should be created.
Adjust the sharpness of turns and crossings	Many users had issues with turning due to turns being to sharp and narrow. It was decided to increase the radius of all turns as well as increasing the road width on some parts of the world.
Find solutions to the lagging	The fact that some parts of the world had a lot of lagging had big affection on the user experience and it was believed that this caused extra simulation sickness for the users. It was decided that a smart solution needed to be found to reduce the lagging and increase the user experience.
Fix car positioning	There was a lot of complaints from users feeling they were tilted and half way out of the car. This probably increased their simulation sickness and needed to be fixed.

6.3.3   Prototyping

All prototyping in this iteration was made in Hi-Fi using Unity and Blender.

Lagging solutions
This problem was difficult to solve. None of the developers had experience in building a world as large as this one and had never needed to be concerned with optimization. A lot of effort was spent searching tips on websites, asking colleagues for tips and watching YouTube tutorials. Colleagues explained that focus should be on: *Occlusion culling, cutting planes, baked lightning, Level Of Detail-groups.*

The biggest issue causing the lagging was that a world this big obviously contains a lot of object, and each object has a number of vertices and triangles. The total number being generated affects the number of Frames Per Second (FPS) of the program. All of this statistics could be seen in the stats panel from the Unity game window so that progress could easily be followed.

Through the use of *occlusion culling*, the program will only generate what the camera actually sees. If something is not in the FOV, it is not generated. Also, by using the right settings, large objects can "block" whatever is behind it, since the objects behind it will not be visible to the camera. This was taken advantage of by having settings that resulted in buildings blocking what is behind them, and using a lot of high trees with a large cube behind them blocking everything on the other side of it.

Cutting planes decide how far the camera will see. By decreasing this value from its previous value of 5000 meters to 700 meters, a lot less objects were being rendered

Another good tip was to use Level Of Detail-groups. This means that an object consists of several objects with different level of detail, generating only one of them depending on how close the user it to it. This means that buildings that are far away will not be in the highest possible resolution and might consist of only a small portion of the original number of vertices and triangles. Lower detail leveled versions of the buildings were created using Blender and then Level Of Detail-groups were created using the new objects. This resulted in a lot less vertices and triangles in the game and a lot better performance.

The differences in statistics from the previous iteration can be seen in Figure 6.26 below, where the "Tris" is the triangles and "Verts" is the vertices.

Figure 6.26: Iteration 2 statistics from the shopping area to the left, and Iteration 3 statistics to the right

Buildings, environment & surroundings

To create surroundings was a planned action to do soon and since it was also asked by the users it was now high time to start building the surroundings. Two building package assets were bought from the Unity asset store, one package containing small neighbourhood houses and garages along with other small things and one package containing city building along with other city stuff. One package containing nature assets such as trees and plants was also downloaded from Unity asset store.

Due to issues with lagging because of the downloaded assets being of to high detail, big parts of the world was built up of woods. These woods were actually a large green cube surrounded by trees in order to work well with occlusion culling. This is visualized in Figure 6.27.
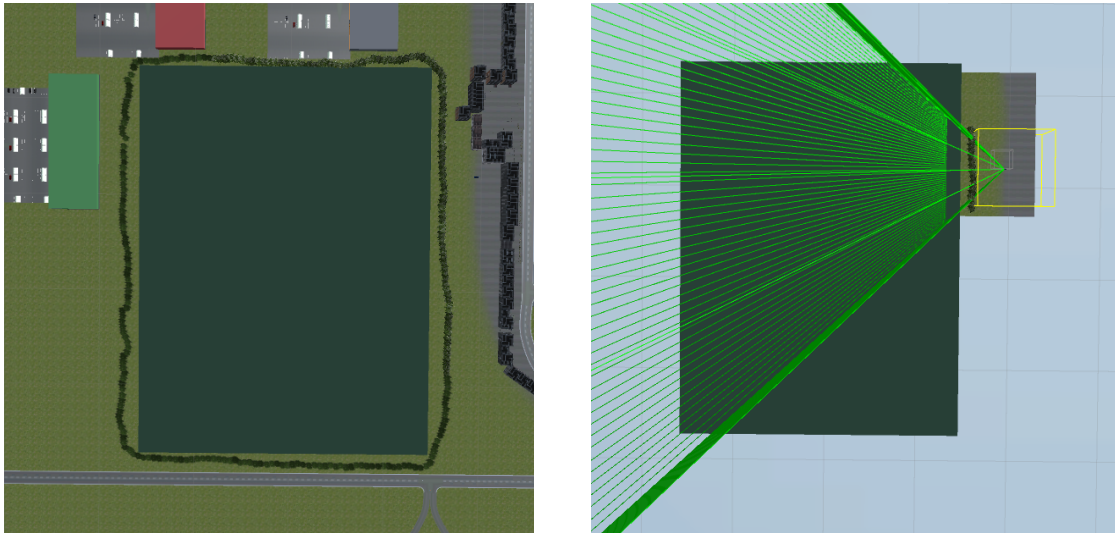
Figure 6.27: The left shows how the world is built and the right shows what is rendered from that position

In the city the occlusion culling worked very well with the high buildings, while the houses in the small family neighbourhoods needed more solutions to reduce lagging. This is why Level Of Detail-groups needed to be created for these houses using functions in Blender.

To solve issues of lagging due to high detailed plants and trees in the country area the solution was simply to use the ones with fewest amount of triangles and vertices and let most parts of the field be of only dirt. Images from each area of the world in its current state can be seen in Figure 6.28 below.
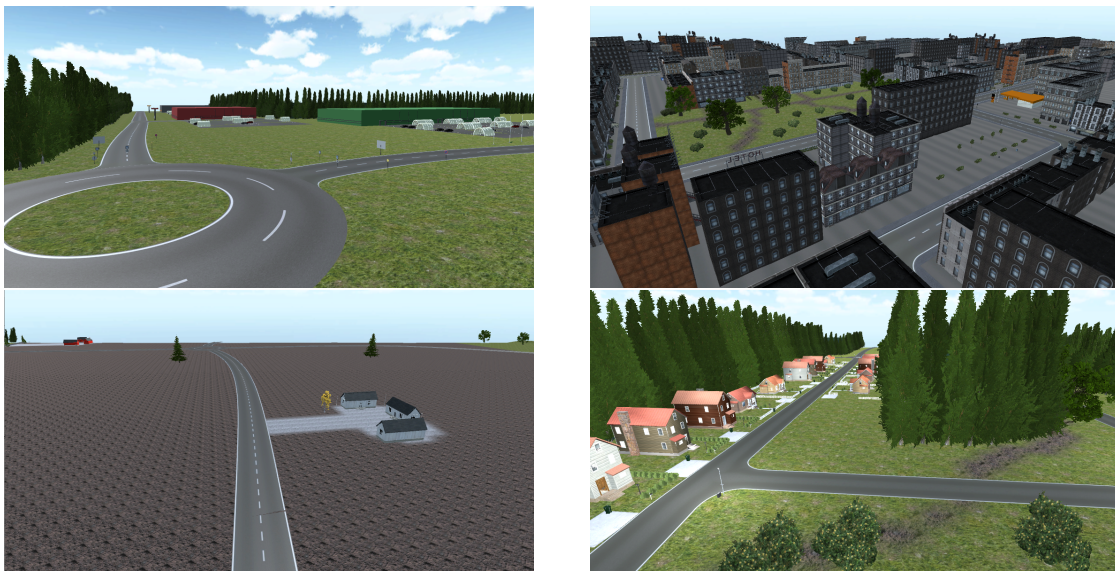
Figure 6.28: The current look of the four areas of the world

Car positioning

During the tests in Iteration 2 some of the testers experienced their positioning in the car to be off and some even experienced that they were sitting with their head half way out of the car.

It was noticed after the test that the camera in the car was tilted by 20 degrees, which was immediately set to 0 degrees. The scale of the camera was also changed from x: 1, y: 1, z: 1 to x: 1.2, y: 1.2, z: 1.2. This made the car size feel more realistic and the feeling of actually being inside the car was improved.

It was also noticed that the camera has two cutting planes. One far cutting plane which was set to 5000 meters and one near cutting plane which was set to 0.3 meters. By changing the near cutting plane to the lowest possible value, of 0.01 meters, it did not feel as if you were half way out of the car while driving. The difference from the previous version in Iteration 2 can be seen in Figure 6.29.

Figure 6.29: Iteration 2 version of sitting inside the car to the left, and Iteration 3 version to the right

Turns & crossings

This was a quick and easy fix in the world. By updating each crossing and turn to have a radius of 5 meters instead of the previous 1 meters the turns were immediately less sharp. However, in the city area, traffic light intersections still felt way to sharp and therefore the road width in the city area was updated to 12 meters instead of 8 meters. This was due to the fact that the road building asset had limited its turn radius to 5 meters, while real traffic roads usually have a turn radius greater than this. The old and the new traffic light intersections can be seen in Figure 6.30.
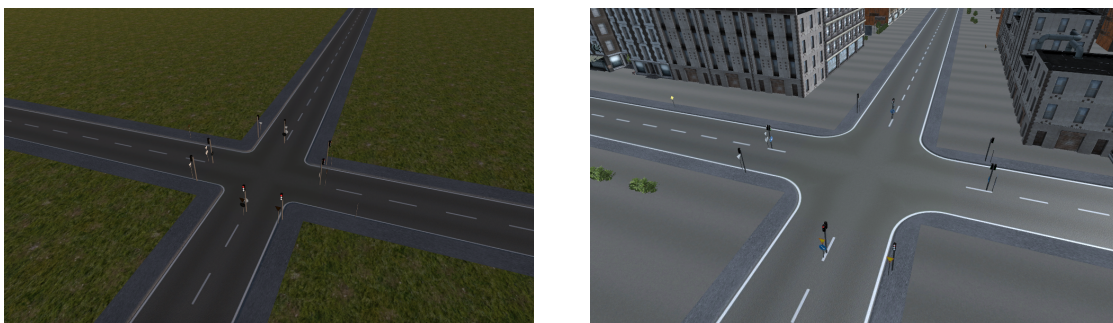
Figure 6.30: Iteration 2 version of traffic light intersection to the left, and Iteration 3 version to the right

6.3.4   Testing

The tests in Iteration 3 was similar to the tests in Iteration 2. The six test participants could drive around in the world to get the feeling of driving in the real world. The difference during this test

was that a test leader directed them a bit to make sure then drove in every kind of area. Figure 6.31 shows the setup and the screen shows both what the driver sees and the part rendered (as in Figure 6.27).

Figure 6.31: Test setup for the third test
.

Quotes during the third test:

- "Huge different since last time!"

- "It it a good sign that my muscle memory wants to turn on the turn signal lights when I am going to turn, this shows that it feels like a real car"

- "This can already be shown to people"

The questionnaire after this test differed in one question. Instead of asking about the road size, it was now asked about the environment. Figure 6.32 shows the results about the environment and Figure 6.33 about the simulation sickness during the third test session.

Question 1.

Did you experience the environment and surroundings to be realistically built?
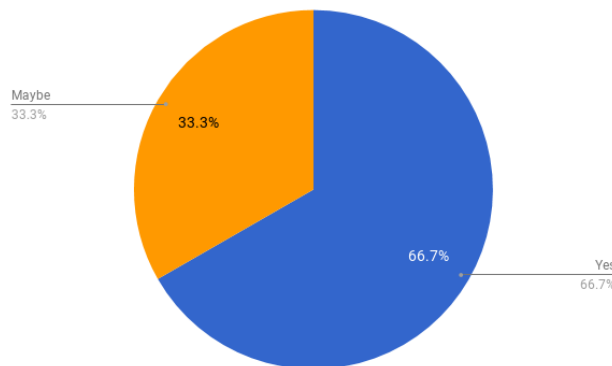
Figure 6.32: What the testers thought about the environment and surroundings after Iteration 3

- "It feels like I am driving on the country side"

Question 2.

Did you experience any simulation sickness or other discomfort from performing this test?
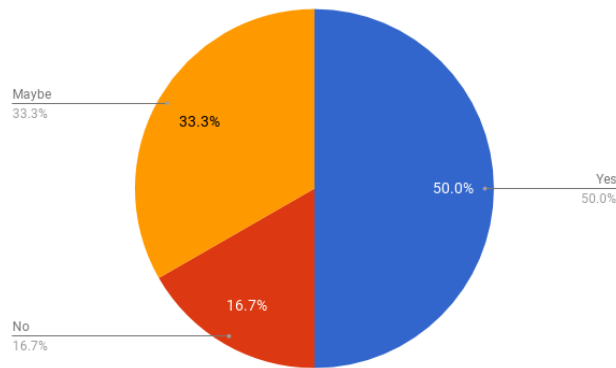
Figure 6.33: Simulation sickness during the third tests

- "Is the chair moving or am I getting dizzy?"

Issues

- The steering wheel covers the instrument panel

- No turn signal lights

- The drivers placement in the car could be improved

- The breaks, both placement and inputs

- Still some lagging problems in some areas

Suggestions

- Add other cars

- Map the buttons on the physical steering wheel to buttons in the virtual car and use them for e.g. turn signal lights

6.4   Iteration 4

This was a short and very special iteration. The iteration was one week long with the purpose of only creating a new intro scene.

6.4.1   Observation

From the previous iteration some testers pointed out that they wanted the buttons in the virtual car to be mapped to the buttons on the physical steering wheel. To make sure that the user understand the mapping a short tutorial should be created in the new intro scene. In this scene the user should also be able to choose a driving mode later on.

6.4.2   Idea generation

Table 6.4: The main idea from the brainstorming in Iteration 4

	Explanation
Create intro scene	Since it should be possible to select different driving modes, an intro scene was built. In this scene the user would be able to select one of the driving modes: Regular driving, night driving and rain driving. The reason different modes was included was because the most important scenario to include in the simulator was driving in the dark (see Figure 5.3). In this scene there was also a short tutorial on how to use the car (such as wipers and turn signal lights) since this was very unclear to the testers.

6.4.3   Prototyping

Since it was desired to have different modes to drive in, an intro scene was created. In this scene the user have the opportunity to choose between three driving modes: day driving, driving the dark or a driving in rain. In the Intro scene a short tutorial to show the user how to use the car was developed. Here the user is taught how to turn on and off the turn signal lights, switch between full and dipped beam, use the wipers and turn the radio on and off. After completing one step in the tutorial, the next step starts so the user tries every step before driving in the world.

The tutorial part of this scene was needed since the Logitech equipment (see Section 3.5) layout does not really match the layout of a real car, which is what the user is used to. Images of the Intro scene tutorial and how the mode is selected can be seen in Figure 6.34 below.

Figure 6.34: Image of the instructions to the left, image of how to pick a mode to the right

6.4.4 Testing

During this test the five users started in the Intro scene and were asked to do whatever they wanted. All of them performed the steps from the tutorial and selected a driving mode, but many of them had issues pressing the right buttons and many did not actually see the highlighted buttons indicating what to click. Some even pressed buttons existing on the Figure 3.2 steering wheel which are not visible in the simulator and thought they pressed the correct button. This indicated the mapping of the buttons to not be quite good enough yet. Only two questions were asked and the answers to the first is illustrated in Figure 6.35 below. The quote for Question 2 below is the only response to the second question.

Question 1.
Did you experience the Intro scene to be instructive and rewarding?
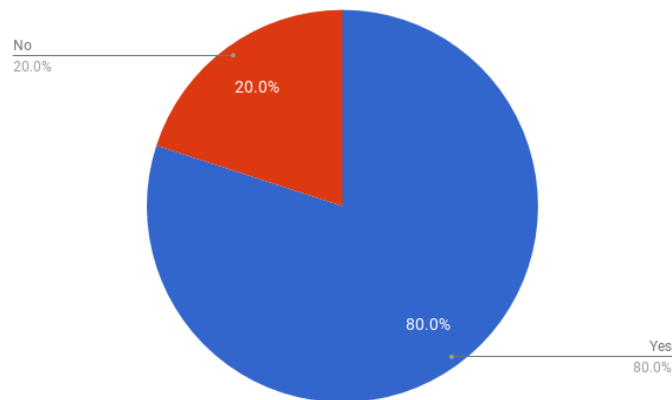
Figure 6.35: Intro scene question 1 result, how rewarding the Intro scene were for the users

Question 2.
If No or Maybe, please explain

> - *"I did see highlights on some of the buttons, but not on all."*

Issues

- Users did not notice the highlighted buttons

- Users did not know what they were meant to do

- Users click the wrong buttons

Suggestions

- Make the highlighted buttons more noticeable

- Add the other buttons from the real steering wheel to the steering wheel in the simulator

6.5 Iteration 5

The main goal for Iteration 5 was to build traffic in the world and improve the Intro scene. The iteration was extended from the regular two week iteration length to three weeks due to difficulties in implementation.

6.5.1 Observation

Many of the testers gave suggestions to add some other cars to make the traffic feel more realistic. Most of the issues from Iteration 3 felt small and could be solved quickly to leave more time to create the traffic in the world and improve the Intro scene, as suggested from Iteration 4.

6.5.2 Idea generation

Table 6.5: The main ideas from the brainstorming in Iteration 5

	Explanation
Build traffic	As a first step it was decided just to make some cars drive around in the world. The second step was to add some intelligence to the cars so they would stop for traffic lights, drive within the speed limit and not drive into surrounding objects.
Fix car positioning	There was still some complaints about the positioning in the car, mostly because the testers could not see the speed pointer and therefore could not test their ability to maintain the current speed.
Add buttons to steering wheel	Many users asked for improvements to the steering wheel. To improve the mapping of the buttons on the steering wheel all the buttons was created
Improve intro scene	It was difficult for many of the users to notice the highlighted buttons. This needed to be improved.

6.5.3 Prototyping

Traffic
As described above, traffic was needed to be included to take the prototype to the next level.

Figure 6.36: The white thin line is the drawn path for the car to follow
.

By placing empty game objects along the road and then combining them with a line, a driving path could be drawn, see Figure 6.36. Several different driving paths were created to each area of the world. After this, cars were placed on the paths. Each car was given a node as a starting point on their path. Now the world had some traffic. The problem now was that the cars did not know any traffic rules. So the next step was to give the cars some intelligence.

This was done by creating trigger points. Trigger points are, in this case, cube game objects without a mesh renderer, meaning they will not be visible and they can be driven right through. By adding tags to these cubes, the cars driving in to them can detect what type of an object they have collided with by checking the tag in the script. Some examples of created tags for the trigger points are "max50", "max30", "brake", "slowdown" etc. The car can then act accordingly to the tag of the colliding trigger point. Trigger points were also activated and deactivated depending on other cars being close or a traffic light showing a red or a green light for example. Figure 6.37 shows an example of trigger points in a traffic light intersection. Note that the green lines will not show when in game mode.
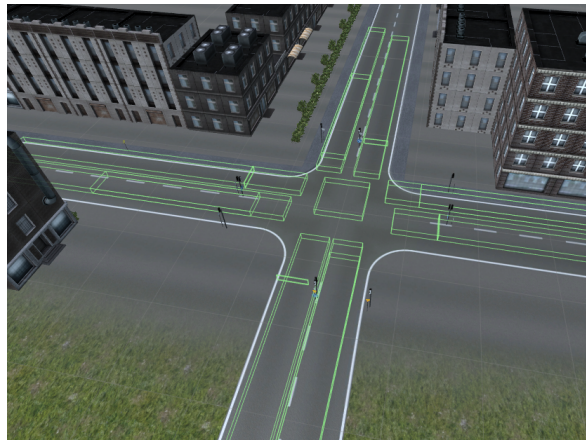
Figure 6.37: Example of trigger points in a traffic light intersection
.

Car positioning
The issue with the car positioning being a bit off is most likely due to the Playseat Evolution Alcantara drivers seat (see Section 3.6) moving around a small bit each time a tester sits down or get up from the seat. The problem with not being able to see the speed pointer could however be solved by moving the virtual steering wheel up a small bit and increase its size so that the user can see the speed pointer through the steering wheel as shown in Figure 6.38.

Figure 6.38: The new positioning and size of the steering wheel
.

Steering wheel buttons

Since the Logitech steering wheel used in this project (see Section 3.5) is targeted toward car games it comes with a lot of buttons. Most of these buttons are completely different from a real car steering wheel. Those buttons who were not different were implemented to be as similar to a real car steering wheel as possible. This led to turning on and off the main beam was done by using the button behind the steering wheel to the left, and turning on and off the windscreen wipers was done by using the button behind the steering wheel to the right.

The blinkers, radio, menu and menu selection buttons where used by using regular buttons on the steering wheel. Navigation in the menu was used by using the navigation pad on the steering wheel. The buttons in the simulator were mapped as accordingly as possible to the Logitech steering wheel to make it easy for the user to find the correct button. The Logitech steering wheel and the simulator steering wheel can be seen in Figure 6.39.

Figure 6.39: The Logitech steering wheel [26] to the left, the simulator steering wheel to the right

Intro scene

To improve the Intro scene a new, more noticeable highlight color, see Figure 6.40, was used to make it easier for the user to notice it. Also, the result of adding all buttons to the steering wheel helped with feedback. The user could now see which button was pressed immediately so it was easier to see if the highlighted button moved when the user pressed a button.

Figure 6.40: The new highlighted color

6.5.4 Testing

The tests in Iteration 5 were performed in the same manner as the previous test on five users. The participants generally completed the tutorial with less problems than the test in Iteration 4. Some issues with the other driving cars appeared, such as driving past a red light, crashing and getting stuck.

<div align="center">- "It's very tight with all the small buttons"</div>

<div align="center">- "The resolution of the Occulus makes it difficult to read the speed pointer"</div>

<div align="center">- "I don't think about what speed I drive in unless i see the other cars"</div>

The questionnaire after this test was different from the previous one in one question. Instead of asking about the environment it was now asked about the other cars and intro scene, Figure 6.41 - 6.42 together with the quotes presents the result for the Iteration 5 test.

Question 1.
Did you experience the other cars in the world to drive in a realistic way?
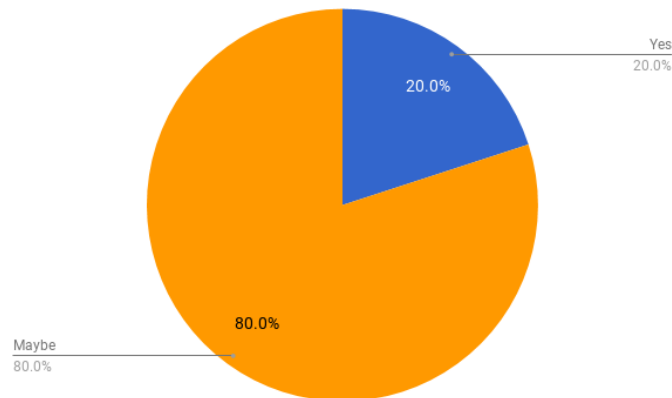
Figure 6.41: The other cars in the world drove somewhat realistic, according to the test participants

<div align="center">- "They moved realistically. But some of them wouldn't stop for red lights."</div>

Question 2.
Did you experience the intro scene to be instructive and rewarding?

All five testers said that they found the Intro scene to be rewarding.

Question 3.

Did you experience any simulation sickness or other discomfort from performing this test?
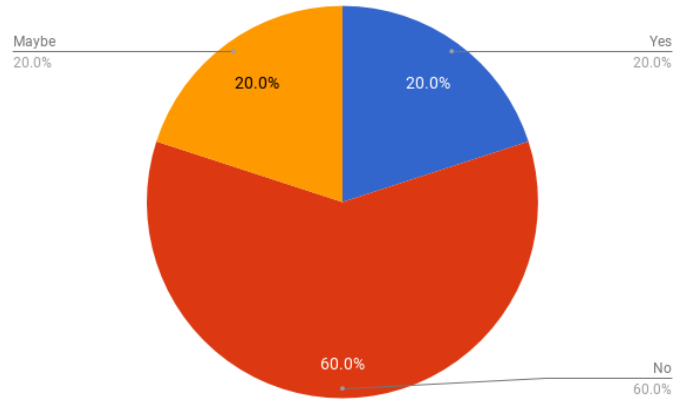
Figure 6.42: Simulation sickness during the fourth tests

Issues

- Still difficult to see current speed

- The other cars are not driving perfectly

Suggestions

- Add display for the current speed

- Add people in the environment

6.6 Iteration 6

The last iteration for the development was extended to four weeks, because it was mainly to fix bugs and add the last components to the virtual environment.

6.6.1 Observation

An issue from Iteration 5 was that it was still difficult to see your current speed. One suggestion to fix this was to add a digital speed display as a complement to the speed pointer. To increase the presence for the simulator, the social presence [17] could be increased by adding people to the world and adding a instructor.

6.6.2 Idea generation

Table 6.6: Ideas for the last iteration

	Explanation
Add people	To increase the social presence, people could be added to the world. It was also necessary for the people to feel realistic, and not just be static bodies. Therefore the people had to be able to move.
Fix speed display	Since it was hard to see what speed one was traveling in, an idea of adding a digital display came up.
Instructor	Another feature to add was the idea of having a driving instructor beside you in the car. This instructor would be guiding the user.
Special situation	The idea of implementing some sort of special situation was given from our supervisor. Adding a cell phone that started to ring during the simulation to see how the user kept their focus when something unexpected happens was suggested.
Improve other cars	Solve the previous issues of the other cars

6.6.3 Prototyping

People in the world
As described in Section 2.4, presence is hard to define, but it is important for the experience. To increase the social presence, people were added to the world and especially by adding a driving instructor that talks to you social presence can be achieved. At this state, the people had only been added in the city area. Figure 6.43 shows people standing in a small area. On other areas in the city, people are walking around to make it more realistic.

Figure 6.43: People in the city standing in a small area
.

Speed display

From Iteration 5, testers still thought it was hard to see what speed he or she was traveling in. Therefore a digital display was added next to the speed pointer, in the center of the dashboard, see Figure 6.44. That way the user can get the visual feedback of the speed in two different ways.

Figure 6.44: The new speed display
.

Instructor

To make it feel more like the user actually were driving at a driving school, an instructor was placed in the passenger seat. During the final tests the instructor guided the driver through the world and kept an eye on the speed.

- *"Think about the speed"*

- *"Turn left at next crossing"*

These were two examples said by the instructor during the drive.

Trigger situation

To give the user an opportunity to practice focus, a cell phone was built, see Figure 6.45. This phone was placed next to the gear box. At a certain point the phone starts to ring and might make the user lose focus on the road. At the same time as the phone rings, a person runs out on the street in front of the car. If the driver loses focus, he or she might hit that person. There are four different trigger points placed in the virtual world, but only one can be triggered each drive.

Figure 6.45: The ringing phone that might distract the user
.

Improve other cars

Before this iteration some bugs with the other cars still existed. Fixing these bugs made the cars always stop at a red traffic light, always stop at a duty to stop and knowing when to stop at a give away place.

CHAPTER 7

Evaluation Phase

This final phase of the project is where all sub questions should be answered. This was done by collecting data from tests which could then be used to answer the sub questions who can then answer main question. The phase consisted of four parts: Prepare data collection, Prepare final test, Test implementation and Evaluate result. Each part of the phase as well as the result of each part is presented below.

7.1 Prepare data collection

The main question, ***"Can a VR environment be realistic enough for a driving student to actually benefit from using it?"*** will be answered using four sub questions.
To decide on how data should be collected, each of the sub questions was went through. Each question should be covered by at least one data collection type from each of the four data types as described in Section 4.3.1. Below, each of the sub questions and its data collection type is presented with a motivation of why these data collection types were used.

Can we make the user convinced that they actually are driving a car?

Table 7.1: Data collection for the first sub question

	Quantitative	**Qualitative**
Subjective	How convinced did you feel that you were actually driving a car?	What similarities and differences did you experience from driving a real car?
Objective	Count the number of deviations the user makes from normal driving?	Quotes about the driving

The most important data for this sub question is the subjective-quantitative one. This one shows black on white if the user actually felt convinced that they were driving a car. A theory was that a user that is convinced that they are driving a car might not brake many traffic rules. The deviations observed during the tests were:

- User does not use turn signal lights

- User does not stop at a red traffic light

- User driver travels more than 20km/h over the speed limit

- User drives into another car intentionally

- User drives off road intentionally

- User does not stop at a duty to stop

- User does not slow down before a give away place

Quotes gave much valuable information such as if the driving felt realistic or that the driving felt odd. Asking about similarities and differences from driving a real car provided information about if the most important aspects were included in the simulator or if the simulator was missing something very important from real driving.

Does the user feel that VR actually improves the presence or can a regular driving simulator perform the same level of presence?

Table 7.2: Data collection for the second sub question

	Quantitative	**Qualitative**
Subjective	How convinced were you that you were actually in a car while driving in VR? How convinced were you that you were actually in a car while driving with a 2D screen?	Describe what you experienced to be the largest differences in driving with a VR HMD vs with a 2D screen
Objective	Count the number of questions the user asks while driving in VR vs 2D	Observations of how the user reacts to for example crashing in VR vs 2D

Once again the subjective-quantitative question gave very direct information about how convinced the user was from driving in VR vs 2D which could be seen directly in numbers. Here the subjective-qualitative also gave very valuable and direct information about the differences between VR and 2D and if VR actually was experienced to be better. There was a theory in the objective-quantitative data collection that a user that is more immersed in a fictional world would forget about its real surroundings and therefore ask less questions.

Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?

Table 7.3: Data collection for the third sub question

	Quantitative	**Qualitative**
Subjective	Are there any situations which you now feel more prepared for in traffic after using the VR simulator?	In what way do you feel more prepared for real traffic after using the VR simulator?
Objective	How many people react in the staged "unusual" situations?	What are the reactions and actions of the tests in the staged "unusual" situations?

To answer this question the objective-quantitative was the one giving the most valuable information. Mainly to see if the user was reacting at all or the staged situation did not feel realistic enough. If the user did feel that the situation was realistic, the subjective-qualitative question would help answering

if the user feels more prepared for driving in the real world.

Is there a reason for why this have not been implemented yet seeing how there is such a large interest in the project?

Table 7.4: Data collection for the forth sub question

	Quantitative	**Qualitative**
Subjective	How much motion sickness or discomfort did you experience from using the VR simulator?	What would you say might be the drawbacks of using a VR simulator?
Objective	Count the number of people who say something is unnatural while using a VR simulator	Quotes about the driving

As described in Section 2.9 simulation sickness is a common effect of using VR. This was also described from the developers of VRoom (see Section 1.4.1) to be an issue from using their product. Simulation sickness was also explained as a big issue from the vice chairman of STR (see section 1.4.2). Because of this background information there was a theory that the simulation sickness is the reason for why this product does not exist today. This is why the subjective-quantitative question was very important to be able to answer this sub question. If the theory about simulation sickness would be wrong, the subjective-qualitative question would help answer what the issue really is, if any. By listening to what the user describes as unnatural, valuable data that the user himself might forget will still be collected.

7.2 Prepare final test

To be able to execute the final test, more preparation was made in comparison to previous tests. It was decided to test the simulator in VR as well as with a 2D screen, since one of the sub questions compares VR to regular driving simulators. Test plan, observation protocols and questionnaires was created to make sure that all data needed was collected. The test plan consists of all parts to perform during the tests. The sub questions and how to answer them, as described above, is also included here. From this it was clear that enough data would be collected to answer the sub questions and therefore the main question. The full test plan can be seen in Appendix C.

7.3 Test implementation

The aim of the testing was to execute tests on 20 participants. Due to some participants not showing up, the final count was 17 participants. There were also hopes that tests could be performed on driving school instructors and driving school students, but due to accessibility to the office, only one driving school instructor participated and zero driving school students. Most participants were colleagues from the Jayway office with driving experience, which was fine since they all knew how a car experience should actually feel.

All tests were performed in the same room, under the same conditions, and with the same steps. The participant was first asked to fill out a briefing questionnaire (see Appendix D) and then the test leader read from a script where he explained the test implementation. The test leader asked the participant to think out loud during the drive, explained the purpose of the test, its risks and that the participant could cancel the test whenever he or she wanted. The participant then signed a non-disclosure agreement and was ready to start the test.

Half of the participants drove in VR first and the other half drove with a 2D screen first, as seen in Figure 7.1. The driving equipment and world was the same in both cases. During the test the test leader was silent and stood behind the participant. The observer sat further back in the room and filled out the observation protocol, which can be seen in Appendix E, during the tests.

Figure 7.1: Testing in VR to the left, testing with 2D screen to the right

During the test, the driving instructor in the simulation told the participant where to drive. This led the participant to all different areas in the world. The tests took approximately 30 minutes to complete.

After the test the user filled out a debriefing questionnaire which can be seen in Appendix F. The results from briefing, observations and debriefing is shown in Chapter 8, Figure 8.1 - 8.3, Table 8.1 - 8.10 and quotes.

CHAPTER 8

Evaluation Phase - Results

After the tests, data from a total of 17 participants had been collected. To evaluate the result from this data each of the sub questions was discussed along with the data that was meant to answer the questions from Section 7.1. The subjective-quantitative data could be observed directly from the results of the questionnaires. Data from the observation protocol was put together in a Google Sheets to see if any useful data could be used. After discussing the importance of each of the data collection types for each question, a common agreement on the answers to the sub questions could be settled. These answers will be discussed further in Chapter 9.

8.1 Briefing

Question 1.
Have you used VR before?

Options: Yes or No
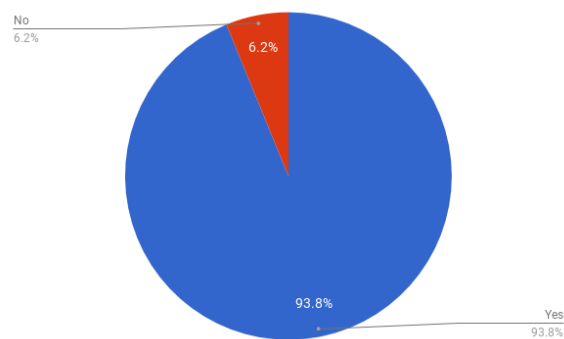
Figure 8.1: How many of the test participants have tried VR before

Question 2.
Do you have any connection to a driving school?

Options: Instructor, Student or No
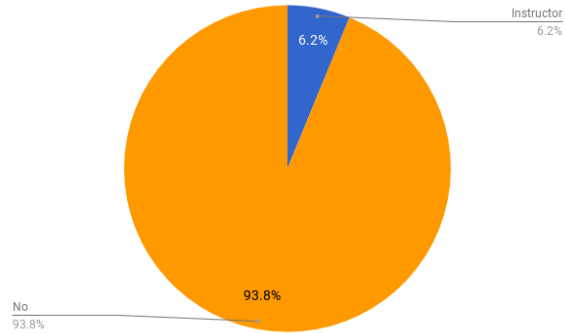
Figure 8.2: Does the test participants have a connection to a driving school?

Question 3.
Do you have a driving license?

Options: Yes or No
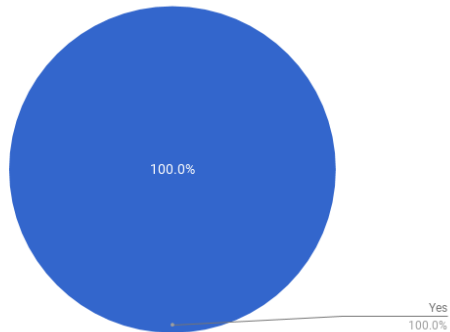
Figure 8.3: Does the tester have a driving license?

8.2   Observations

Average number of deviations from regular driving:

Table 8.1: Number of deviations during the test for VR and 2D

VR	2D
1	1.94

The most common deviation in both VR and 2D was traveling over the speed limit. In VR 47% drove to fast at some point and in 2D it was just over 70%.

Average number of questions while driving:

Table 8.2: Average number of questions asked in VR and 2D

VR	2D
2.82	3.18

Average number of reacting to the staged "unusual" situation:

Table 8.3: How many users that reacted to the unusual situation

VR	2D
76%	71%

Number of participants expressing something is unnatural while driving in VR:

Table 8.4: Percentage of the test participants expressing something felt unnatural

VR
41%

Quotes about the driving with 2D screen:

- *"It's difficult to get a good overview since I'm used to turning my head."*

- *"My spontaneous thought is that I want to see how the world works. For example, should I follow the traffic rules or should I start driving into road signs."*

- *"It feels as if I am crawling forward in the speed of a snail."*

Quotes about the driving with VR HMD:

- *"The text looks very blurry. I can barely read the road signs."*

- *"VR works a thousand times better than 2D. The fact that you can look around gives a complete new dimension to the simulator and looking around your surroundings is just what driving is about."*

- *"It's strange to not feel the physical feedback of the car that you're used to."*

Observations of how the user reacts to for example crashing in VR vs 2D:
Some of the most common observations from the tests were:

- Participants tend to drive faster in 2D than with a VR HMD

- Participants tend to speak much less when driving in VR

- Many participants talked to the driving school tutor while in VR, but not at all in 2D

- Participants seemed to have a harder time staying withing the road lines when driving in 2D, especially when turning

- Participants over viewed their surroundings much more when driving in VR

Some of the most common observations from the staged "unusual" situation were:

- Participants slowed down both in VR and when driving in 2D

- Participants cross braked both in VR and when driving in 2D

- Participants looked down at the ringing phone when driving VR

- Participants said "What was that?"

8.3 Debriefing

Question 1.

How convinced did you feel that you were actually traveling in a car during the test (VR) considering all aspects of the current simulator?

Table 8.5: How convinced the users felt while driving in VR

Not at all	1	2	3	4	5	Completely
	0%	11.8%	29.4%	58.8%	0%	

Question 2.

How convinced did you feel that you were actually traveling in a car during the test (2D screen) considering all aspects of the current simulator?

Table 8.6: How convinced the users felt while driving with a 2D screen

Not at all	1	2	3	4	5	Completely
	47.1%	35.3%	17.6%	0%	0%	

Describe what you experienced to be the largest differences in driving with a VR HMD vs with a 2D screen:

Most participants answered this question by mentioning the ability to look around you to observer your surroundings.

> - "In VR it was way easier to get a broader perspective of you surroundings which made things like turning and parking more natural. To observe your surroundings is such a big part of driving so this felt very good in VR compared to 2D."

Question 3.

What similarities and differences did you experience from driving a real car when driving in VR?

Differences

> - "The lack of physical feedback when accelerating, braking and turning is surprisingly noticeable."

> - " Expecting the pull in turns that didn't exist, i.e. in a real car you can feel how far into a turn you are while in the simulation you had to rely on mostly one sense: vision."

> - " Nausea upon every turn and breaking."

Similarities

> *- " In VR the free look part was very similar to what it is and really how important it is in real life. Having an interior and a driving wheel (both graphical and real) which resembled a real car helped to make me believe i was driving a real car after a (for me very short) time of adapting to VR."*

> *- " Feels like you're driving, concerned about your safety (safety measures)."*

> *- "The experience as a whole is very similar"*

Question 4.
Are there any situations which you now feel more prepared for in traffic after using the VR simulator?

Table 8.7: If the testers felt more prepared for any situation after the test

Yes	No	Maybe
23.5%	53.0%	23.5%

If yes or maybe above, please give examples

> *- "Incoming calls and distractions."*

> *- "Need to keep focus and oversight."*

Question 5.
How much motion sickness or discomfort did you experience from using the VR simulator?

Table 8.8: Simulation sickness during final tests

Not at all	1	2	3	4	5	6	7	8	9	10	Extreme
	11.8%	29.4%	17.6%	0%	5.9%	5.9%	17.6%	5.9%	5.9%	0%	

Question 6.
What would you say might be the drawbacks of using a VR simulator?

> *- "The physical aspect which can't be simulated."*

> *- "Can only rely on visual and audio senses."*

> *- "The simulation sickness"*

> *- "It's more of a complement not a replacement of driving real cars. Lack of car movement, handling and details (like more traffic)"*

Question 7.
Would you consider using the simulator in its current state as a complement to practice driving?

Table 8.9: If the simulator can be used as a complement to regular practice driving

Yes	No	Maybe
70.6%	5.9%	23.5%

Question 8.
Do you prefer to drive in VR or 2D Screen?

Table 8.10: Which of VR and 2D is the most popular

VR	2D screen
76.5%	23.5%

Question 9.
Did you think that the simulator was missing anything?

- A horn

- More realistic steering wheel, to many buttons

- The feel of speed needs to be improved

- More like a driving school, driving lessons, traffic rule lessons

Other comments about the prototype:

> - "The VR experience felt much more real than I thought, and I was much more engaged thus careful in the experience."

CHAPTER 9

Discussion

We will discuss each of our sub questions separately and present arguments and counterarguments for each one of them. We will also discuss the importance of each argument to reach a conclusion which will then be presented in Chapter 10. The limitations of VR driving simulators will be presented and the possibilities for future work will be discussed.

During our final tests, seven out of the 17 test participants had tried the simulator at least once before. Because of this, some of the results might have been affected, such as simulation sickness. This is because users who are experienced with VR usually do not experience as much simulation sickness as beginners. Even though this might affect the results, we have chosen not to take this into account while analyzing the results. This is because we can not prove that it has affected the final result.

Can we make the user convinced that they actually are driving a car?

As we have already described in Section 7.1 the most important data to answer this question is the result from Table 8.5. This result shows black on white if the user actually felt convinced that they were driving a car during the simulation. Since the result showed that almost 60% of the users rated the simulation at a 4 out of 5 and an average of 3.47 out of 5 we believe that, considering only this data, the users felt fairly convinced that they were driving a car. If the average would be a 4 or higher, we would say that the users definitely felt convinced considering only this data.

Our results from the debriefing as well as observed quotations showed that the most commonly experienced difference from driving a real car was the lack of physical feedback. As mentioned in Section 2.9 our vision is our strongest sense. Because of this one might think that a user should actually feel convinced that they are driving a car, but because of the conflict between the vision and the physical feedback this sometimes leads to the users experiencing simulation sickness instead. We believe that since nausea is a rare reaction to driving a real car, this affects how convinced the users are. The lack of physical feedback was an expected issue already pointed out in the Research phase of the project from the previous developers of VRoom (see Section 1.4.1) and STR (see Section 1.4.2). If we only look at this data we would say that the users are not convinced that they are actually driving a car. Since the physical feedback is an important part of reaching immersion we think that this data also has high impact on the conclusion.

We consider that an average of 1 deviation or less would be a result that motivates that a user is convinced that they are actually driving a car. When driving in VR the average deviation count was 1, with the most common deviation being overspeeding. The second most common deviation was forgetting to use blinkers, which in our case is not really an odd behaviour since the blinkers affordance on the steering wheel is not very natural for the user. So, considering only this data we would say that the users are convinced that they are driving a car, because the average deviation count is 1 or less. Also, since the blinkers affordance is bad, we believe that we got worse results than what we should have gotten if the steering wheel would have the same layout as a real steering wheel. Also,

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overspeeding by 20km/h is something we consider to actually be common when people is driving real cars. Even though the average of one deviation shows that the user is convinced that they are actually driving a car, we do not think that this data has as great impact on the conclusion as the previous two. We think that the differences in affordance and physical feedback from driving a real car are the reasons why we can not reach an average of 4 or higher in the result of Table 8.5.

Does the user feel that VR actually improves the presence or can a regular driving simulator perform the same level of presence?

Just as in the previous question we here have a subjective-quantitative question that gives us black on white how convinced the user felt during the VR experience compared to driving with a 2D screen. Table 8.5 shows us an average of 3.47 out of 5 while driving in VR and an average of 1.71 out of 5 while driving with a 2D screen, where almost 50% voted 1. We think that considering only this data it is extremely clear that VR improves the presence compared to driving with a 2D screen.

Almost every test participant mentioned in the debriefing that the largest difference in driving in VR compared to with a 2D screen is the ability to look around and observing your surroundings. During the observations there were also a quote explaining how VR gave a complete new dimension to the simulator. We think that these responses argues that VR actually improves the presence, considering only these data.

We had a theory that a user who is more immersed in a virtual environment would ask less questions. Looking at our results from Table 8.2 we can see that the average question count only differs by 0.36 in favour of VR. We believe that, considering only this data, the difference is way to small to say that VR would improve the presence. We think that in order to say that VR would improve the presence the average question count for driving in 2D would need to be the double amount of the average for VR.

Some interesting observations from the tests were that the test participants were much more silent while driving in VR and spoke to their driving school instructor. We think this shows that they excluded us and instead interacted with the people in the virtual environment which shows that some level of social presence (see Section 2.4) was achieved.

Considering this we would say that a higher level of presence is achieved while driving in VR.

Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?

The subjective-quantitative results from the debriefing shows that 53% of the test participants does not feel more prepared for any particular traffic situations after using the VR simulator. Out of those who answered either yes or maybe, the most common situation they now felt prepared for was incoming calls and distractions. This is exactly what we expected. The fact that 53% of the test participants answered no is of course a worse result than what we expected since we believe that preparing users for rare situations is one of the main advantages of a VR simulator. Based on only these results we can not argue whether or not the test participants feel more prepared for rare situations in the future. When driving in VR 76% of the test participant showed some sort of reaction to the staged rare situation. The fact that we made 76% react to the situation but only 23.5% feel more prepared for the situation in the future implies that we have actually managed to create a rare situation, it is just not effective enough. Based on the reaction from 76% of the users we would say that we can use a VR environment to simulate rare situations to the user.

Since this staged situation was developed in our last iteration we never had time to test it on users before the final tests. We believe that if we would have had the time to test it first, we could have improved the staged situation. In the final prototype the situation is fixed and not based on any outer parameters such as the driver's speed. If there would have been more time the distance from the trigger point to the running person would have been based on the speed of the car to create a more

effective rare situation. By creating a more dramatized experience the product would have moved further down in Edgar Dale's Cone of Experience (see Figure 2.1) and the user would have learned more from this experience. If we would have done this we believe that we could have increased the number of reactions to almost 100% and the number of participants feeling more prepared for the situation would have increased as well.

Even though our results show that users do not feel more prepared for rare situations, we believe that a VR environment can make the users more prepared for rare situations in the future by creating more effective situations.

Is there a reason for why this have not been implemented yet seeing how there is such a large interest in the project?

From the start of this project we have been warned that simulation sickness is the major issue of developing a driving simulator in VR. Because of this we have continuously checked on the level of simulation sickness during each iteration of the project and tried to lower it each iteration. As shown in Figure 9.1 simulation sickness has decreased during the project. During Iteration 1 to Iteration 3 and Iteration 5 the test participants were asked to answer yes, no or maybe while we wanted to get a better overview in the final tests, which is why we instead asked for a number between one and ten. Simulation sickness was not measured during Iteration 4 since that iteration only looked at the Intro scene. The calculations in the chart below counts a yes as a multiple of 1, a maybe is a multiple of 0.5 and a no is a multiple of 0. In the final test we decided that a rating of one to four is a no, a five or six is a maybe and a seven to ten is a yes.
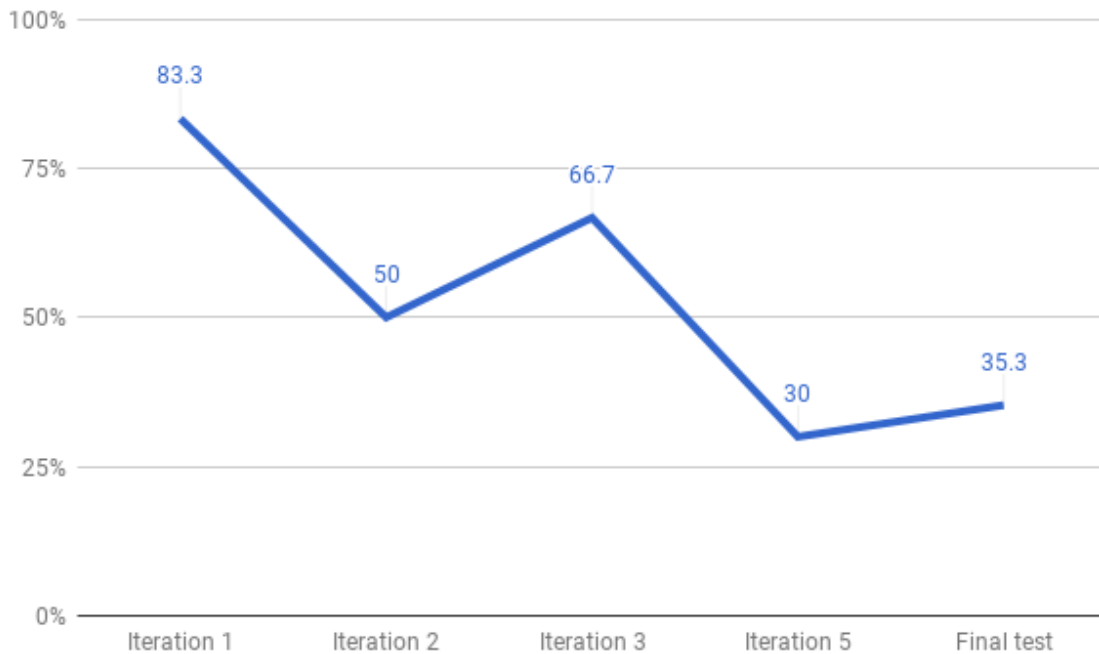

Figure 9.1: The development of simulation sickness from Iteration 1 to the final test

Based on this result 35.5% would probably not be able to use the simulator, which is why we believe that simulation sickness is a big reason for why this has not been developed yet. However, looking at the trend of the curve, we believe that with more time we would be able to lower the simulation sickness ratio to a lower and much more acceptable value.

41% of the test participants said that something felt unnatural while driving in VR and most of the test participant pointed out the physical feedback as the largest drawback of using the VR simulator. Quotes about the physical feedback being an issue was also observed during many of the tests. In order to get this physical feedback, much more expensive equipment would need to be used. Even then, the physical feedback would not be perfect. By using equipment with this sort of physical feedback we believe that the simulation sickness ratio would go down even further. However, because of how costly this equipment would be, this is most likely one of the reasons why this product does not exist today.

9.1 Limitations

Looking at the situation as it is today we believe that the biggest limitations in a VR car simulator is the hardware as well as simulating the human factor.

Even though there have been a lot of development in the area, the best HMDs today still do not have a high enough resolution to display truly realistic objects. Also, even the best GPUs today have a hard time rendering many high resolution objects simultaneously without dropping in FPS. Our tests have showed that lower FPS can lead to more simulation sickness.

As our results, as well as the previous work showed, the lack of physical feedback is a huge limitation in VR driving simulators. Section 1.4.5 presents a simulator with a lot of physical feedback, but this equipment is very expensive and still has a hard time simulating acceleration forces.

To simulate the human factor in a good way is extremely difficult, if not impossible, to achieve. In the case of a driving simulator, the human factor needs to exist with other drivers as well as pedestrians. AI (Artificial Intelligence) will make drivers and people understand how they should act, not how they should not act, which is why the human factor will be so difficult to achieve.

9.2 Future work

-"Great potential. Possibility to be a good complement for practising before taking your driver license"

This is a product that many people can not understand why it does not exist today. Many think it has great potential and are very interested in the product. For future work we think that the most important improvement to implement is increasing the physical feedback of the simulator, which might also result in a lower simulation sickness ratio. During the development of this project many have requested more driving school theory as well as a more "gamified" driving experience with some sort of score system. We think that a further development of this product should include more driving theory and the option to drive in a more "gamified" driving mode. We believe that this sort of product will never be complete. There will always be more features that can be included to make the experience better.

CHAPTER 10

Conclusion

Can we make the user convinced that they actually are driving a car?

Yes. We can make the user convinced that they are actually driving a car with VR equipment. The 3.47 out of 5 convincing ratio from Table 8.5 has a greater impact than the fact that some users experience simulation sickness while driving in VR.

Does the user feel that VR actually improves the presence or can a regular driving simulator perform the same level of presence?

Yes. The user feels that VR improves the presence compared to driving with a 2D screen. The 3.47 VR ratio (see Table 8.5) compared to 1.71 2D ratio (see Table 8.6) proves this very clearly. Also, the fact that users excluded the surroundings and interacted with the fictional characters in VR proves a higher level of presence in VR.

Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?

Yes. We have managed to create rare traffic situations using the virtual environment. No. The users do not feel more prepared for the situations in the future. However, by developing the rare situations in a more effective way, they very well might.

Is there a reason for why this have not been implemented yet seeing how there is such a large interest in the project?

Simulation sickness, lack of physical feedback and cost. The simulation sickness and lack of physical feedback was clearly a problem during the tests, and costly equipment is the best way to get around these issues.

Can a VR environment be realistic enough for a driving student to actually benefit from using it?

There are more positive sides to a VR driving simulator than there are negative ones. The most negative aspects of a VR simulator is the lack of physical feedback which sometimes results in simulation sickness, missing the human factor and some users will drive the simulator more like it is a game. One of the most positive aspects of using a VR simulator is that the students can practise to overview their surroundings when driving. Other positive aspects of a VR simulator is that is is cheap to use, free of risk, it can simulate rare situations and it brings in another dimension in comparison to other driving simulators.

In conclusion:
A VR environment can be realistic enough for a driving student to benefit from using it. A VR environment can make the user convinced that they are driving a car, it can improve the presence compared to driving with a 2D screen and it can simulate rare situations for the user. Once there is good enough equipment for this, at a reasonable price, this sort of simulators will probably be a common complement to practise driving at most driving schools. With all aspects in mind, and with the result from all sub questions, we would say that a VR simulator is a good complement to practise driving but it is not a good replacement and will probably never be a replacement to regular practise driving. This is a product we think that driving schools should use and we believe that driving school students would benefit from using a VR driving school simulator.

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Appendices

APPENDIX A

Interviews

A.1 Driving school students

Question: *Hur länge har du övningskört?*
Translation: *How long have you practiced driving?*

Question: *Vilka trafiksituationer upplever du vara svårast/jobbigast när du övningskör?*
Translation: *What situations do you experience to be the most difficult/tough when you drive a car?*

Question: *Vad är det som är det jobbiga i situationen?*
Translation: *What is it that is difficult in this situation?*

A.2 Driving instructors

Question: *Vilka situationer är det vanligast att dina elever har problem med?*
Translation: *Which situations does your students experience most difficulties with?*

Question: *Vad tror du är det största problemet för eleverna i situationen?*
Translation: *What do you think is the greatest problem for your students in this situation?*

Question: *Varför tror du detta är det största problemet för eleverna?*
Translation: *Why do you believe this is the greatest problem for the students?*

Question: *Vad tror du är det bästa sättet att minska elevens svårigheter i dessa situationerna?*
Translation: *What to you believe would be the best way of minimizing the students difficulties in these situations?*

APPENDIX B

Questionnaires

B.1 Driving schools

Question: *Finns det situationer som eleverna oftast inte får uppleva under sin tid hos körskolan?*
Translation: *Are there any situations that the driving students most likely never experience during their time at the driving school?*
Question: *Finns det intresse hos er om att använda sig av en VR simulator som komplement till vanliga körlektioner?*
Possible answers:

- Ja
- Nej
- Vet inte

Translation: *Is there an interest from your driving school to use a VR driving simulator as a complement to the regular driving lessons?*
Possible answers:

- Yes
- No
- Do not know

Question: *Vilka av nedanstående situationer tycker du är viktigast att få med i simulatorn?*
Possible answers:

- Mörkerkörning
- Parkering
- Väjningsplik & stoppplikt
- Högerregeln
- Dåliga väderförhållanden
- Motorväg
- Trafikljus
- Utryckningsfordon
- Cirkulationsplats
- Enkelriktade vägar
- Panikbromsa
- Halka

Translation: *Which of these situations do you think is the most important to include in the simulator?*
Possible answers:

- Driving in darkness
- Parking
- Duty to give away or stop
- The right-side rule
- Bad weather conditions
- Highway driving
- Traffic lights
- Emergency vehicles
- Traffic circle
- One way streets
- Slam on the breaks
- Skidpan driving

B.2 Driving school students

Question: *Vilka av följande områden har du aldrig upplevt när du övningskört?*
Possible answers:

- Mörkerkörning
- Parkering
- Väjningsplik & stoppplikt
- Högerregeln
- Dåliga väderförhållanden
- Motorväg
- Trafikljus
- Utryckningsfordon
- Cirkulationsplats
- Enkelriktade vägar
- Panikbromsa
- Halka

Translation: *Which of these situations have you never experienced while practice driving?*
Possible answers:

- Driving in darkness
- Parking
- Duty to give away or stop
- The right-side rule
- Bad weather conditions
- Highway driving
- Traffic lights
- Emergency vehicles
- Traffic circle
- One way streets
- Slam on the breaks
- Skidpan driving

Question: *Vilka av följande områden känner du dig mest osäker på när du kör bil i trafiken?*
Possible answers:

- Mörkerkörning
- Parkering
- Väjningsplik & stoppplikt
- Högerregeln
- Dåliga väderförhållanden
- Motorväg
- Trafikljus
- Utryckningsfordon
- Cirkulationsplats
- Enkelriktade vägar
- Panikbromsa
- Halka

Translation: *Which of these situations do you feel most insecure while driving in traffic?*
Possible answers:

- Driving in darkness
- Parking
- Duty to give away or stop
- The right-side rule
- Bad weather conditions
- Highway driving
- Traffic lights
- Emergency vehicles
- Traffic circle
- One way streets
- Slam on the breaks
- Skidpan driving

Question: *Vilka av följande områden tycker du borde vara med i en körskolesimulator i VR?*
Possible answers:

- Mörkerkörning
- Parkering
- Väjningsplik & stoppplikt
- Högerregeln

- Dåliga väderförhållanden
- Motorväg
- Trafikljus
- Utryckningsfordon

- Cirkulationsplats
- Enkelriktade vägar
- Panikbromsa
- Halka

Translation: *Which of these situations do you feel should be included in a VR simulator for practice driving?*
Possible answers:

- Driving in darkness
- Parking
- Duty to give away or stop
- The right-side rule

- Bad weather conditions
- Highway driving
- Traffic lights
- Emergency vehicles

- Traffic circle
- One way streets
- Slam on the breaks
- Skidpan driving

Question: *Hade du tyckt att det vore givande med en VR-körskolesimulator på din körskola som komplement till de vanliga körlektionerna?*
Possible answers:

- Ja
- Nej
- Vet inte

Translation: *Do you feel that a VR simulator for practice driving would be a good complement to the regular driving lessons?*
Possible answers:

- Yes
- No
- Do not know

Question: *Hur länge har du övningskört?*
Possible answers:

- Aldrig
- Mindre än ett halvår

- Mindre än en vecka
- Mindre än ett år

- Mindre än en månad
- Mer än ett år

Translation: *For how long have you been practiced driving?*
Possible answers:

- Never
- Less than half a year

- Less than a week
- Less than a year

- Less than a month
- More than a year

APPENDIX C

Test plan

To be able to answer the project's main question, tests needs to be performed.

1. **Purpose**
   This test will simulate a traffic network with four different areas. City, highway, country roads and family neighborhood. The goal is to see if this simulator can be used as a complement to regular driving. It will also be tested if it is beneficial to use a VR setup compare to a normal computer screen. The test subjects will therefore be divided into two groups, where group 1 will drive in VR first and then normal computer screen, and group 2 the other way around.

2. **Formulation of questions**

   - Can we make the user convinced that they actually are driving a car?
   - Does the user feels that VR actually improves the presence or can a regular driving simulator perform the same level of presence?
   - Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?
   - Is there a reason for why this hasn't been implemented yet seeing how there is such a large interest in the project?

3. **Data capture**

   (a) **Can we make the user convinced that they actually are driving a car?**

(b) **Does the user feel that VR actually improves the presence or can a regular driving simulator perform the same level of presence?**

Qualitative data

Describe what you experienced to be the largest differences in driving in VR compared to with a 2D screen

Observations of how the test person reacts to certain situations while in VR compared to while using a 2D screen

Preference data ← → Performance data

On a scale from 1-5, how convinced were you that you were actually in a car while driving in VR?
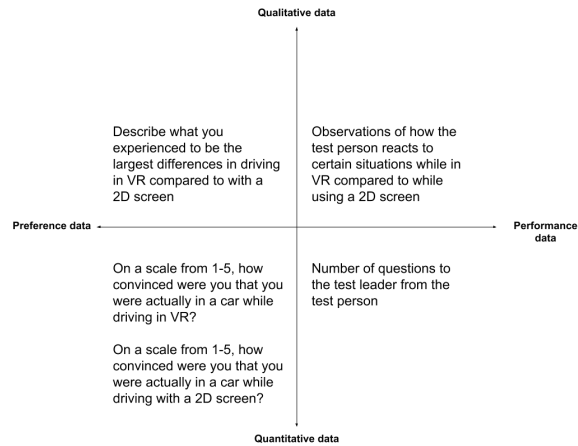
Number of questions to the test leader from the test person

On a scale from 1-5, how convinced were you that you were actually in a car while driving with a 2D screen?

Quantitative data

(c) **Can we use a VR environment to simulate rare situations to the user and if so, will the user feel more prepared for them in the future?**

Qualitative data

In what way do you feel more prepared for real traffic after using the VR simulator?

Observations of how the test person reacts and acts when experiencing the created "rare" traffic situations

Preference data ← → Performance data

Are there any situations which you now feel more prepared for in traffic after using the VR simulator (Yes, No or Maybe)?

Number of persons reacting to the created "rare" traffic situations

Quantitative data

(d) **Is there a reason for why this hasn't been implemented yet seeing how there is such a large interest in the project?**

Qualitative data

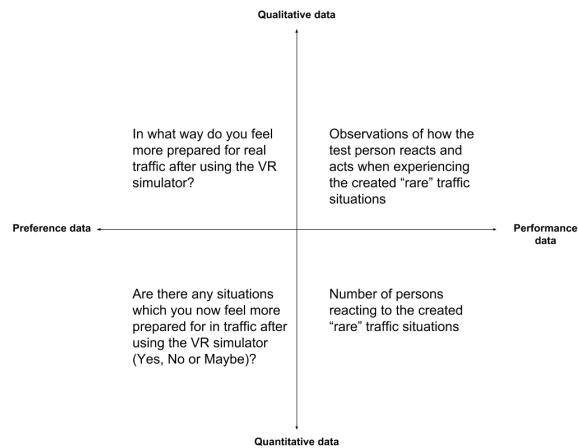What would you say might be the drawbacks of using a VR simulator?

Quotes

Preference data

Performance data

On a scale from 1-10, how much motion sickness or discomfort did you experience from using the VR simulator?

Number of persons expressing something to feel unnatural while using the VR simulator

Quantitative data

4. **Test tasks**

Table C.1: Test tasks to be performed

Task	Subtasks	Time
1. Drive in the **VE!** (**VE!**)	Follow the driving instructors instructions	max $10min$
2. Drive with a 2D screen	Follow the instructions given by the test leader	max $10min$

5. **Implementation of test**

Table C.2: The different parts of the final tests

Phase	Part of phase	Materials	Time
Briefing	Give the test subject an introduction to the aim with the test and how to use the equipment during the test	List of notes that needs to be told to the test subject	$5min$
Test tasks	Give the tester a test task to perform and let him/her drive around as they please	Oculus rift Logitech steering wheel and pedals Playseat Evolution Alcantara	$\sim 20min$
Debriefing	Testers answer questionnaires	Questions both in subjective and objective form, to get as good result as possible	$5-10min$

6. **Test environment**
   The tests will be held at Jayway in Malmö. The primary room to use is the VR-lab, but if needed, small conference rooms can be used for the briefing and debriefing.

7. **Casting**

   - **Test Leader:**
     Will be head of the test and give the test subject it tasks and keep track of the time for each task. He will also be briefing the subjects before the tests and ask the subjects to approve to use the recordings as a part of the study.

   - **Data collection responsible:**
     Collect and analyzing all the objective data during the tests.

   - **Debriefer:**
     Giving the subjects the questions that will be answers after the test.

8. **Test subjects**
   This simulator can be tested by anyone that got a drivers license. The primary test subjects are people that are connected to driving schools somehow. Can be both students or driving teachers, since we think that they have the best insight of what can be used within driving schools. Secondary testers are anyone with driving licence, they know how the traffic works and can answer if they feel that the simulator is realistic or not. Our hope is to get as many participants from the primary group as possible. During the test, half of the test subjects will first drive in the VE and then on a normal computer screen and other way around for the other half of the test subjects.

9. **Documentation**
   The documentation will be done in two ways, data collections from questionnaires and from capturing quotes from the tests.

APPENDIX D

Briefing questionnaire

Question: *Have you used VR before?*
Possible answers:

- Yes

- No

Question: *Do you have any connection to a driving school? (e.g you are a student or an instructor)*
Possible answers:

- Instructor

- Student

- No

- Other

Question: *Do you have a driving license?*
Possible answers:

- Yes

- No

APPENDIX E

Observation protocol

The observation protocol was divided into two parts, one for 2D and one for VR. The protocols them self was written the same and was formed as follows:

- User does not use turn signal lights (Yes/No)

- User does not stop at a red traffic light (Yes/No)

- User driver travels more than 20km/h over the speed limit (Yes/No)

- User drives into another car intentionally (Yes/No)

- User drives off road intentionally (Yes/No)

- User does not stop at a must stop (Yes/No)

- User does not slow down before a give away place (Yes/No)

Number of questions asked during the test

Look down at the cell phone when it rang (Yes/no)

Reaction when person ran crossed the road (Yes/No)

What kind of reaction when crash into an object

Reaction and action when person ran crossed the road

Quotes

APPENDIX **F**

Debriefing questionnaire

Started with:

- VR

- 2D

How convinced did you feel that you were actually traveling in a car during the test (VR) considering all aspects of the current simulator?

Not at all | 1 2 3 4 5 | Completely

How convinced did you feel that you were actually traveling in a car during the test (2D screen) considering all aspects of the current simulator?

Not at all | 1 2 3 4 5 | Completely

Describe what you experienced to be the largest differences in driving with a VR HMD vs with a 2D screen

What similarities and differences did you experience from driving a real car?

Are there any situations which you now feel more prepared for in traffic after using the VR simulator?

- Yes

- No

- Maybe

If yes or maybe above, please give examples

How much motion sickness or discomfort did you experience from using the VR simulator?

Not at all | 1 2 3 4 5 6 7 8 9 10 | Extreme

What would you say might be the drawbacks of using a VR simulator?

Would you consider using the simulator in its current state as a complement to practice driving?

- Yes

- No

- Maybe

Do you perfer to drive in VR or 2D Screen?

- VR

- 2D

Did you think that the simulator was missing anything?

Other comments about the prototype