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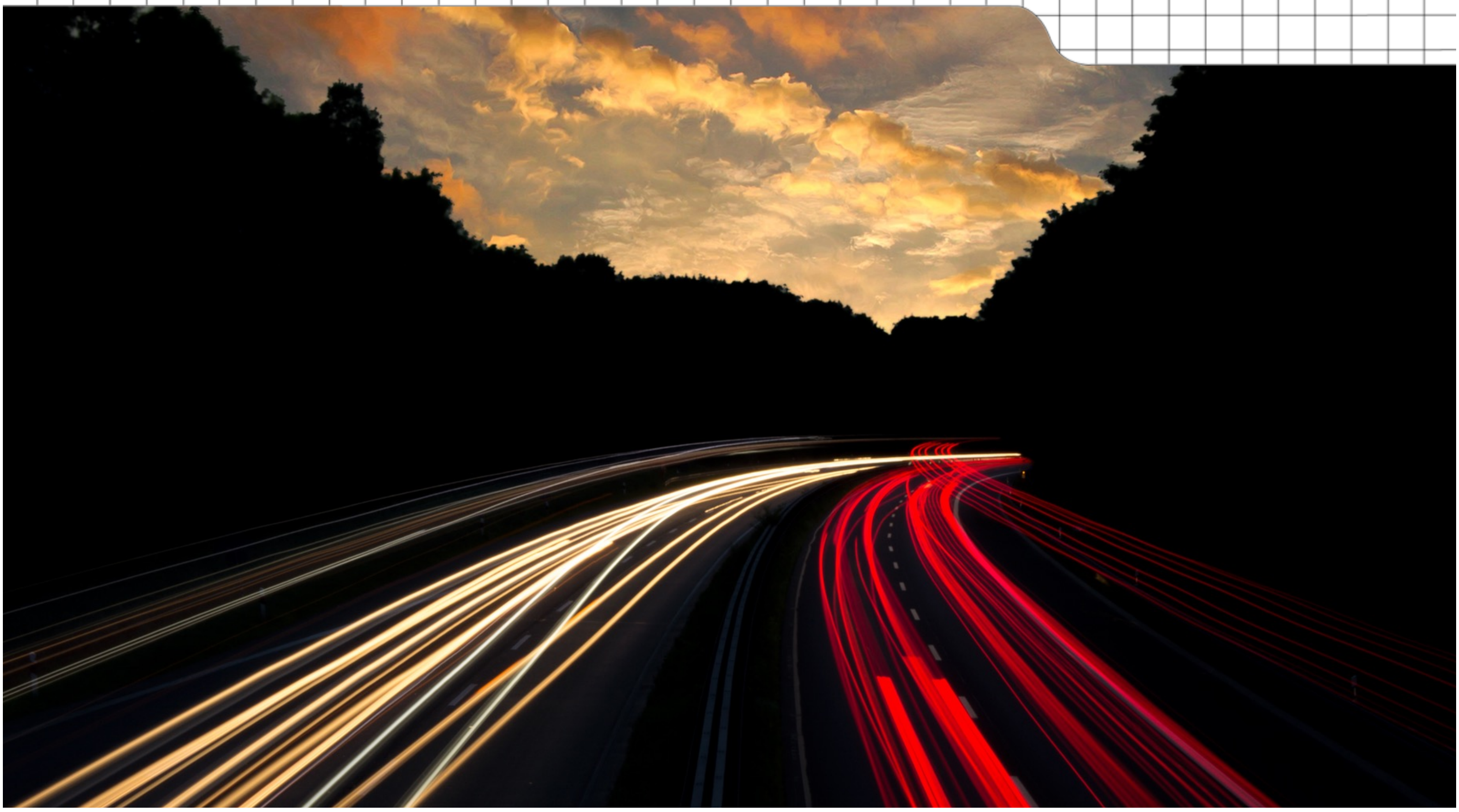

Using Virtual Reality in an Automotive User Experience Development Process

An investigation of how to use head mounted display VR when evaluating digital interfaces

Master of Science Thesis in the Master Degree Program, Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Department of Product- and Production Development
Division of Design & Human Factors

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ABSTRACT

The automotive industry of today is characterized by trends towards an increased focus on user experience (UX) and digital interfaces. Development cycles have become shorter, and in order to save time and cost the importance of early concept evaluations has increased. One way to support early UX evaluations of interactive systems, could be to make use of virtual reality (VR), a group of technologies that have developed rapidly during recent years. Due to this situation, Volvo Car Corporation (VCC) requested an investigation with the aim to gain a better understanding for how to utilize VR in user studies related to development of digital driver interfaces.

Based on the investigation, the goal was thereafter to create a design concept that could lead to improved user studies, and also to create guidelines for how to work with VR within the UX field. The investigation consisted of three central parts. The first was a literature study focusing on UX and VR. The second was a user study with 13 participants where VR equipment, a driving simulator, and a real car was tested and compared. Data was collected through interviews and observations, but also through questionnaires such as the UEQ and ICT-SOPI. The last part of the investigation was about identifying user needs among VCC employees that will be involved in studies where VR equipment is used. Based on the investigation, it was considered that one of the areas where the greatest improvements could be made was on the physical rig. Due to this, the concept development phase focused on creating a new rig. The final concept was a VR test rig made as a mobile unit possible to bring to test sites.

Keywords: Virtual Reality (VR), head mounted display (HMD), user experience (UX), automotive industry, digital interfaces, interaction, user-centred design, user study, concept development.

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Gothenburg 21th of May 2017

Magnus Carlsson & Tor Sonesson

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ABBREVIATIONS

VCC - Volvo Car Corporation

VR - Virtual Reality

VE - Virtual Environment

HMD - Head mounted display

CTS VR - Currently Tested Setup of VR

CTS Simulator - Currently Tested Setup of driving simulator

UX - User experience

CSD - Centre Stack Display

DIM - Driver Information Module

HUD - Head-Up-Display

01 INTRODUCTION

This chapter will give an overview of the project. More precisely it will contain a background to why User Experience (UX) is a crucial aspect to consider within the automotive industry, the questions at issue that has to be answered in order to fulfil the aim, and the delimitations of the project.

1.1 BACKGROUND

The automotive industry of today is characterized by trends towards increased focus on User Experience (UX) and digital interfaces. Development cycles are continuously being shortened and workflows are getting more agile (Pettersson, 2016; Weir, 2010). To compete on the premium market UX and usability need to be evaluated early in a design process in order to save time and cost, and to reduce time to market (Lawson, Salanitri, & Waterfield, 2016; Schina, Lazoi, Lombardo, & Corallo, 2016; Bruno & Muzzupappa, 2010).

New technology for creating representations of early concepts have evolved over recent years. One of the new possibilities is to make use of Virtual Reality (VR), a group of technologies that enables users to experience and interact with virtual environments separated from the present physical environment. The technology has potential for assessing UX and usability at early product development stages (Lawson et al., 2016) and due to this fact, many actors in the automotive industry want to get a better understanding for how to best utilize VR in their design process of digital user interfaces.

This master thesis project was initiated by the department Digital User Experience (DUX) at Volvo Car Corporation (VCC) and was carried out in an industrial context. The department is responsible for the UX of the digital content in the car, such as the centre stack display (CSD), the head-up-display (HUD) and the dashboard in front of the driver (DIM).

1.2 AIM

The aim is to gain a better understanding for how to best utilize head mounted display (HMD) VR in user studies within design processes focusing on digital driver interfaces in an automotive setting.

1.3 QUESTIONS AT ISSUE

- Where and how is VR used today?
- What are the limitations and opportunities with HMD VR technology?
- How suitable is the Currently Tested Setup of VR (CTS VR) compared to alternative methods for evaluating the UX of digital interfaces in an automotive setting?
- What guidelines are relevant to consider in user studies using HMD VR?
- How could a conceptual solution, where the guidelines are considered, be embodied?

1.4 DELIMITATIONS

The project covered 30 credits per person. In order to fulfil the aim and answer the questions at issue the following delimitations were made.

- The project will focus on interaction with digital driver interfaces in an automotive setting.
- Other prototyping methods than HMD VR will only be considered briefly.
- Distraction, in terms of the effect on driver attention, will not be considered.
- The created concepts will be based on HMD technology.

1.5 PROCESS OVERVIEW

The project was carried out from a holistic and user centred perspective and followed a traditional iterative design methodology. This approach was chosen since other work about VR mainly focuses on the technology itself rather that the actual user.

02 THEORY

This chapter will present the theoretical framework used as a basis for this project, focusing on the topics UX and VR.

2.1 USER EXPERIENCE (UX)

UX could be described as a subjective phenomenon that occurs when interaction takes place between three components, which are; a user, a product and a context (Hartson & Pyla, 2012; Rebelo, Noriega, Duarte & Soares, 2012). The field goes beyond considering only instrumental aspects and also includes affective ones such as emotion and meaning (Rebelo et al., 2012; Bussolon, 2016). Figure 1 below illustrates the three components which UX consists of (Gkouskos, Pettersson, Karlsson, & Chen, 2015).

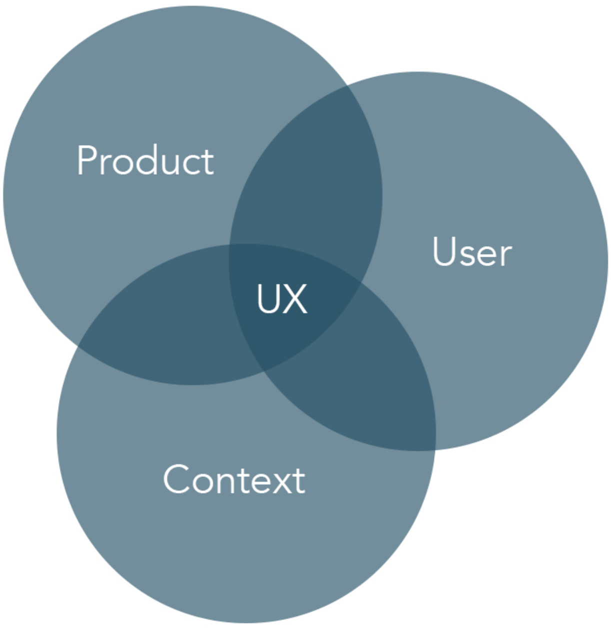


Figure 1. Illustration of the components which UX consists of.

Apart of being described in academic literature, there is also an ISO definition of UX which reads *"a person´s perceptions and responses that result from the use or anticipated use of a product, system or service"*. The definition also states that it regards factors such as *"a user's emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use"* (ISO/DIS 9241-11.2).

UX FROM A DESIGN PERSPECTIVE

From a design perspective UX is about the experiential qualities of technology use rather than product qualities themselves (Hassenzahl, Diefenbach, & Göritz, 2010). Furthermore, it could be argued for that design, related to UX, should be approached holistically. The main reason to this is, as stated by Gkouskos et al. 2015, that *"the richness of human experience cannot be reduced to a set of variables"* and therefore the importance of studying UX as a whole is highlighted.

RELATION BETWEEN UX AND USABILITY

As described in the previous section, UX is a field that contains several sub-topics, both in terms of instrumental aspects and affective ones. One of them is *usability* (Rebelo et al., 2012; Hartson & Pyla, 2012), which could be described as the pragmatic component of UX (Hartson & Pyla, 2012). More in detail, usability regards aspects such as; effectiveness, efficiency, productivity and ease-of-use. The relation between usability and UX is visualized in figure 2.

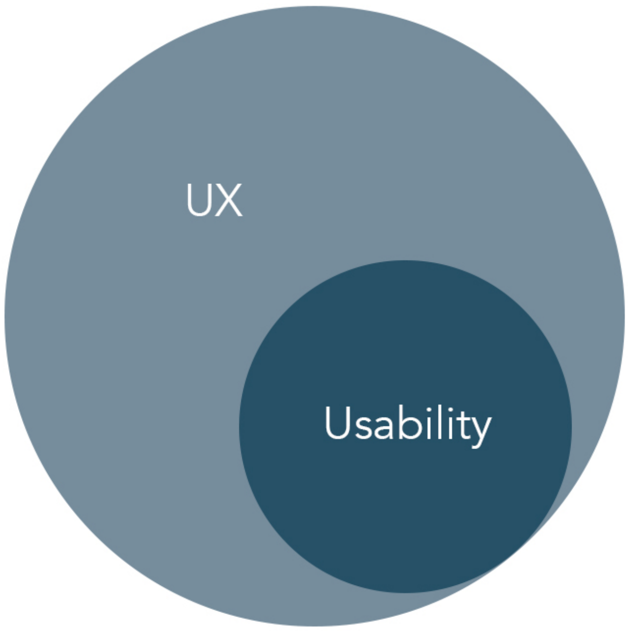


Figure 2. The relation between UX and usability.

As with UX, there is also an ISO standard for usability, defining the term as *"the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO/DIS 9241-11).

UX TESTING IN THE AUTOMOTIVE INDUSTRY

The automotive industry of today is, like many other industries, characterized by trends towards increased connectivity and interactivity. Furthermore, the pace in which the area develops is steadily increasing (Pettersson, 2016; Weir, 2010). A lot of people spend a considerable amount of their time commuting in cars and therefore the UX of the cockpit is highly important (Gkouskos et al., 2015). This has made car manufacturers, especially those in the premium segment, to realize the potential competitiveness of implementing more, and better, interactive systems in their products which in turn has created a growing interest for experiential aspects within the field. Therefore, UX is now considered to be of major importance within this industry which requires more research, as well as a more holistic approach, within the field (Gkouskos et al., 2015).

To evaluate UX, several different methods are used for creating prototypes of concepts that should be tested. Paper prototypes is one of them which is widely used in early development phases (Schneegaß, Pfleging, Kern, & Schmidt, 2011). It is a useful tool for testing designs to identify potential problems (Snyder, 2004; Schneegaß et al., 2011). Digital screen-based prototypes are another established way of testing digital user interfaces. The method could be based on different types of screens, such as tablets or desktop pc-screens, and is useful when testing interactive content. A tool that offers a more realistic test setting is driving simulators. These could consist of everything from a combination of an ordinary chair, a desktop screen and a gaming steering wheel, to a real car or mock-up of a vehicle combined with a surrounding screen with a considerably larger field of view (Kern, 2012). An important advantage with using driving simulators is that they offer the possibility to test concept in critical driving situations that otherwise would have risked the safety of participants if tested in real traffic situations (Underwood, Crundall & Chapman, 2011). However, a negative aspect with driving simulators is that they could cause dizziness and nausea. One last tool that is commonly used when testing designs in the automotive industry is so called *mules*. Mules are real cars equipped with components that are under development. This tool enables testing of new concepts in real driving situations (Latorre & Pointet, 2008).

2.2 THE VR TECHNOLOGY

As mentioned in the introduction, VR could be described as a group of technologies that enables users to experience and interact with virtual environments separated from the present physical environment (Havig, Mcintire, & Geiselman, 2011). By using this statement as a core, VR could therefore include a large number of mediums ranging from simulated environments shown on a common desktop display, to fully immersive virtual 3D environments.

In literature there is a lot of definitions of VR. One of the broadest ones are given by Rebelo et al. (2012) and reads *"In a very broad sense, VR is a way of transporting a person to a reality (i.e., a virtual environment) in which he or she is not physically present but feels like he or she is there"*. Another definition, found in Encyclopaedia Britannica (Lowood, 2017), is more extensive and involves a short description of the technology necessary to experiencing VR. *"Virtual Reality (VR), the use of computer modelling and simulation that enables a person to interact with an artificial three-dimensional (3D) visual or other sensory environment. VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information and are worn as goggles, headsets, gloves, or body suits. In a typical VR format, a user wearing a helmet with a stereoscopic screen view animated images of a simulated environment"*.

With respect to the definitions above, VR will in this report be defined as; *an artificial three-dimensional environment, separated from the present physical environment, in which a user feels present and has the possibility to interact to some extent.*

PRESENCE AND IMMERSION

Two terms that are commonly used within the VR field are presence and immersion. Furthermore, the terms highly affect the VR experience. Due to this it is important to understand their definitions and meaning.

Immersion, which is described by Gorini et al. (2011) and Mihelj and Podobnik (2012), could be explained as the level to which a person feels involved and engaged in a VR experience. The definition that will be used in this report reads as follows; *Immersion could be defined as the sensation of being focused, engaged and deeply mentally involved in a certain activity or event.*

Presence is referred to as a psychological state of being in a place or location (Oxford University Press, 2017; Rebelo et al., 2012; Jerald, 2015). Furthermore Rebelo et al. (2012) and Jerald (2015) highlights that the experienced environment is human made and virtual. The resulting definition that will be used in this report reads as follows; *Presence could be defined as a subjective phenomenon that gives a user the sensation of being physically present in a virtual world, even though the experiences is generated by and/or filtered through human-made technology.*

HISTORY

The idea about Virtual Reality is not new. The first technology to obtain VR was developed in the 1960s (Schina et al., 2016; Mazuryk & Gervautz, 2013; Jerald, 2015). By placing a movable camera in an adjacent room, and a person wearing a headset equipped with tracking technology in another room, it was possible for the person to look around in that room without being physically there (Jerald, 2015).

In the 1990s the demand for VR equipment increased and the development of technology was intensified (Mazuryk & Gervautz, 2013; Jerald, 2015). However, at this time the technology did not meet the demands of the customers which made many VR companies disappear from the market (Jerald, 2015). The main problems were the limitations within computing power and display technology (Drummond et al., 2017).

Even though the market for VR was strongly decreased at this period of time, the development did not stop. In the early 2000s, the technology found new application areas within user-centred design, foremost as a tool when performing user studies (Jerald, 2015).

VR has in recent years become less expensive and enhanced in terms of both hardware and software (Lawson et al., 2016). Due to this it is today used in various fields ranging from product development to entertainment. Furthermore, VR has now reached the consumer market and several big actors within the tech industry are launching their own VR-equipment (Drummond et al., 2017).

VR IN THE AUTOMOTIVE INDUSTRY

In the automotive industry, VR is being widely used for different purposes. One of the main areas where it is suitable is in early testing and concept evaluations (Lawson et al., 2016). According to Bruno & Muzzupappa (2010), who claims that users are able to evaluate usability aspects of products by using VR, it could be seen as a valid alternative to traditional methods when evaluating product interfaces. Through this it is easier to identify and avoid unnecessary errors, resulting in a higher cost efficiency (Lawson et al., 2016; Schina et al., 2016; Bruno & Muzzupappa, 2010). Cost efficiency could also be increased due to the fact that VR could lead to a shorter time-to-market and an increased quality of the end products (Lawson et al., 2016; Bruno & Muzzupappa, 2010).

Another advantage of VR is that it could easily be used to simulate different environments and contexts around the digital driver interfaces themselves. This is important since the automotive context puts high demands on the interfaces when it comes to aspects such as safety and usability (Gkouskos et al., 2015). For example, testing an interface on a desktop display compared to testing it in a real traffic situation would most likely influence the user experience when interacting with the interface.

One more advantage with the technology is that it opens up new possibilities for remote collaboration since it enables 3D-object to be experienced simultaneously on different places (Lawson et al., 2016). This could for example facilitate an increased cultural exchange or to involve users even if they are not physically present at tests (Bruno & Muzzupappa, 2010).

DIFFERENT TYPES OF VR

Literature categorizes VR into three main groups where the level of immersion is the differentiating factor (Rebelo et al., 2012). The least immersive group, called *nonimmersive*, includes virtual environments shown on ordinary desktop screens. The second category, called *semi-immersive*, offers higher level of immersion and often consist of large surrounding projection screens or CAVE systems. The third group, called *fully-immersive,* offers immersive equipment and includes different kind of HMDs and equipment that offers sensory input in various forms. Illustrations representing each category is shown in figure 3.

In the automotive industry, two common types of VR are HMDs and so called CAVEs. HMD systems consist of one or more headsets equipped with screens, together with a positioning system that can track the position and the orientation of the headsets (Havig et al. 2011). Many

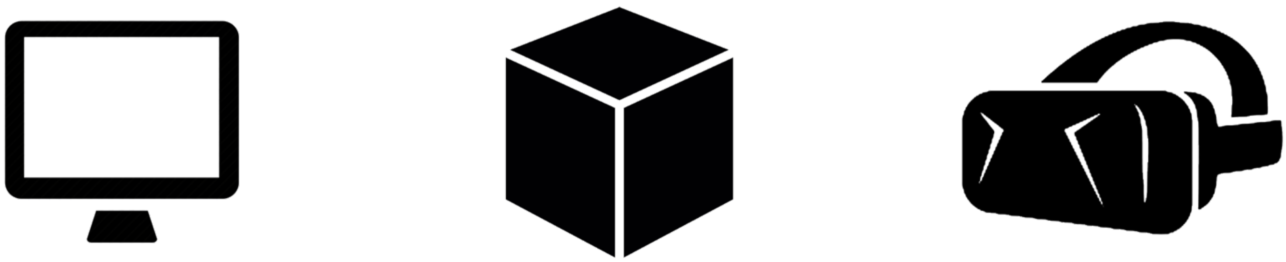


Figure 3. Examples of the three categories of VR; desktop VR, CAVE and HMD.

HMDs also offers stereoscopic screens which enables three-dimensional content to be shown to the user. Furthermore, there are many types of supporting equipment for a lot of HMDs, such as handheld controllers or connected gloves. This equipment could for example be used to enable more types of interaction or to create more types of sensory stimuli.

CAVE systems, which stands for Cave Automatic Virtual Environments, are classified as semi-immersive (Mazuryk & Gervautz, 2013). They are built as rooms formed by three to six displays on which virtual environments can be shown (Havig et al. 2011). This combined with custom goggles enables these systems to show three-dimensional representations of the environments that surrounds the user when being in the CAVE. Furthermore, the technology offers superior resolution compared to today's HMD headsets (Mazuryk & Gervautz, 2013).

2.3 FACTORS AFFECTING THE VR EXPERIENCE

In theory, the optimal VR experience in terms of UX evaluation validity would be to make the experience as similar to real world experiences as possible (Rebelo et al., 2012). In other words, to create one-to-one relationship between the real world and virtual realities where a high-fidelity level would make users believe that they are actually present in that environment. However, the technological development has not gone that far and therefore the technology available today is associated with a lot of limitations. These limitations regard everything from lack of sensory feedback (Lawson et al., 2016) to delays between user input and system output (Rebelo et al., 2012). As a consequence, today's VR experiences can cause negative side effects such as cybersickness, nausea and headache (Jerald, 2015).

Despite these limitations, VR still seems to be a highly immersive medium where users feel a high level of presence. This is for example implied by Estupiñán, Rebelo, Noriega, Ferreira, & Duarte (2014) who claims that VR seems to have a high arousal effect, and also that it makes people more focused. Another argument is that studies has shown that VR can evoke the same type of emotions and reactions as experiences in the real world (Schuemie, van der Straaten, Krijn, & van der Mast, 2001). According to the same source, this has also been shown in several tests where participants with phobias have been exposed to these phobias through VR. For example, it has been shown in tests where participants were exposed to heights, and in others where people got to speak in front of an audience. Another test showed that *"people tend to respond to mediated stimuli as if it were unmediated when they experienced a high level of presence"*.

In the following sub-chapters more detailed descriptions of factors affecting the VR experience will be presented.

BEHAVIOUR OF THE VIRTUAL CONTENT

An overall factor that affects the VR experience is the extent to which a virtual reality behaves like the real world (Rebelo et al., 2012; Schuemie et al., 2001). The reason is basically that our perceptual system has evolved in reality which is therefore the reference for all our sensory experiences (Schuemie et al., 2001). Due to this, it is of major importance to have a close correlation between user input and system output so that a user's actions result in realistic effects on the virtual content (Rebelo et al., 2012; McMahan, Bowman, Zielinski, & Brady, 2012). For example, if you try to grab a virtual object but there is no physical representation of it, a sensory conflict occurs.

VISUAL ASPECTS

There are several factors associated with the visual sense that could have an impact on the VR experience. The overall key is to enable the visual sense to operate in the same way as in reality (Rebelo et al., 2012). Therefore, it is important to enable realistic depth perception as well as a field of view that correspond to reality, which is claimed by Lawson et al. (2016) and Rebelo et al. (2012). Having an accurate head tracking is also important since it makes the whole experience more realistic, and furthermore since it reduces the risk for cybersickness (Rebelo et al., 2012). Scene complexity is another factor that could affect the sense of cybersickness. If it is too high, the risk tends to increase. Regarding the field of view, the most fundamental criteria for mimicking the real world is to ensure that all of the user's field of view is covered with the virtual environment, without leaving any empty fields or frames around that environment.

The paragraph above argued for the importance of shaping the virtual content so that a user's visual sense operates in the same way as in the real world. In other words, it is quite clear that it is important to make virtual content to stimulate the visual sense as if they were real objects. However not all literature advocates that realistic graphics is necessarily the most adequate way of embodying VR content (Havig et al. 2011). Similar statements can be seen for other tools than VR. For example Buskermolen, Terken, Eggen, & van Loenen (2015) claims that a sketchy version of screen-based renderings can elicit more elaborative feedback since it communicates that it is welcomed to give feedback. Due to this it is seen as advantageous to use a sketchy style when performing evaluations early in the design phase. The same theory may be possible to apply when using VR.

Another factor, related to the one described above, is how well the virtual content handles the representation of a user's body parts (Lawson et al., 2016). By creating a visual representation of body parts, such as arms and hands, the VR experience can become considerably more realistic (Rebelo et al., 2012; Lawson et al., 2016). However, the key is not to make the appearance of the representation as similar to the user as possible, but to make it correspond to the user's real body parts in terms of movement, orientation and position in space. By doing so the sense of presence can be quite compelling even if the virtual representation of the body does not match the user's real body in terms of visual aspects (Jerald, 2015). Apart of making the experience more realistic, another advantage with using virtually represented body parts is that it also tends to reduce the risk for cybersickness (Lawson et al., 2016).

AUDITORY ASPECTS

The auditory sense is a central factor when it comes to creating a VR experience. For example, Lawson et al. (2016) claims that it is fundamental when it comes to enhancing the level of immersion. This is also supported by Mihelj and Podobnik (2012) who furthermore claims that audio can be used to create moods and to provide additional information that makes the virtual environment more understandable. However, in order for audio to contribute positively to the experience it must be included in the right way. To succeed with this, there are two primary criterions. First, the audio must be well synchronized with events that occur inside the virtual environment, and second, it must have a spatial dimension, enabling the user to assess directions and distances to audio sources (Rebelo et al., 2012).

As with the visual sense, the auditory sense is able to collect information about remote objects. However, it is not as influenced as the vision when it comes to the orientation of the head (Mihelj & Podobnik 2012). Even though audio can be perceived slightly differently depending on the direction of the head, it is constantly capable of detecting information from any direction.

HAPTIC ASPECTS

One significant way in which humans explore objects in her close proximity is by using the haptic sense (Mihelj & Podobnik 2012). The haptic sense consists of several different types of receptors which could be categorized into two groups. The first is the somatosensory, which regards the skin's ability to detect stimuli, and the second is the kinesthetic, which regards movement, position and forces applied to muscles, tendons and joints. Because of the interplay between those two categories, we have the ability to perceive features such as texture, temperature, shape, weight and viscosity. Another important fact regarding the haptic sense is that it is claimed to be the sense which the human cognitive system relies the most on in cases where there is a sensory conflict with the visual and auditory sense (Mihelj & Podobnik 2012).

Implementing haptic features in VR can facilitate the interaction with virtual objects and enhance immersion (Lawson et al., 2016). On the other hand, the haptic features are often the most challenging part to implement (Mihelj & Podobnik 2012). There are several reasons to this. One of the most significant regards the fact that the haptic sense could be stimulated in a large number of ways. Due to this, it is difficult to find solutions that handle all these formats, regardless if it concerns the weight, temperature or consistency etc. of a virtual object.

One key for the quality and usefulness of haptic features in VR systems is to consider the way in which users are intended to interact with included virtual objects (Mihelj & Podobnik 2012). The reason is that different types of tasks could benefit of different kind of stimuli. For example, if an object is not to be lifted, the weight is probably not very important, and if something is to be used with gloves, the same applies for temperature.

NARRATIVES

One aspect that influences the VR experience, but that is not related to a specific category of the human sensory system, is the use of narratives. Narratives are stories that users can relate to and that could potentially affect the experience (Gorini, Capideville, De Leo, Mantovani, & Riva, 2011). It could therefore be used for different purposes, like creating a mood among users or increasing their level of engagement. Another reason is that it can contribute to the generation of emotional responses which in turn could increase the level of immersion.

TIME

Several studies have shown that the negative side effects caused by using VR is affected by the time during which users are exposed to it (Rebelo et al., 2012). More concretely, longer exposure times seem to result in increased symptoms (Rebelo et al., 2012; Jerald, 2015). However, symptoms tend to decrease if users are either exposed to VR more often, if frequent breaks are provided or if the VR content are optimized to behave as similar as possible to the real world (Rebelo et al., 2012).

03 PROCESS & METHODS

This chapter will describe how this project was carried out by presenting the activities performed and the methods used. This is done in a chronological order categorized after the main phases of the project.

3.1 PROJECT PLANNING

The project was initiated by the creation of a general plan to reach the desired goal specified in the aim. A Gantt chart was used for the purpose to structure the different parts that were going to be carried out during the project. The Gantt chart, offered an overview of the different activities, when they were supposed to start and stop, and which of the activities that should be carried out simultaneously.

3.2 LITERATURE STUDY

The first phase of the project was to conduct a literature study with three main purposes. First of all, it was about gaining a broad understanding for the central topics of the project; in other words UX and VR. Second, it was about investigating earlier research that had been conducted in fields related to this project. Lastly, it was about identifying knowledge gaps to investigate further. The data was primarily collected from academic literature.

After having collected the data, the next step was to analyse it in order to find patterns between the insights gained. This was done by compiling the data into different categories inspired by the Affinity Diagramming method, described by (Martin & Hanington, 2012).

3.3 EXPLORATIVE STUDY

To complement the literature study, an explorative study was performed in parallel with it. This study had a more hands-on characteristic with the purpose to gain an increased experience of the VR-technology and its application areas. The experience was gained by performing visits both at the DUX department and externally.

OBSERVING VR EQUIPMENT AT DUX

One of the activities performed during this phase was to observe and test VR-equipment at DUX department that had been developed for showcasing new concepts of in-car interactive systems. The observations regarded both hardware and software, including how to control it as a whole. This was done during visits at VCC's concept centre where CTS VR was currently placed. Apart of exploring the equipment on own hand, communication was also made with employees working with it, in order to gain more detailed information and instructions about how to handle the equipment.

OBSERVING VR EQUIPMENT AT OTHER VCC DEPARTMENTS

Another activity was to visit different departments at VCC and talk to employees involved in VR at these departments. Visits were made at the Design department, the Ergonomics department and the Innovation team at the IT department. This was done for two main reasons. First, to map what equipment that are currently used internally at VCC, and second, to learn about previously identified difficulties and opportunities.

OBSERVING VR EQUIPMENT AT EXTERNAL ACTORS

Lastly visits were also made at Lindholmen Visual Arena, an open and neutral collaboration platform for the development and use of visualization. Two visits were made there. The first included a semi-structured interview with a technician responsible for their VR-equipment and the second visit included participation in an event called Gothenburg VR meetup. This event included talks from tech companies and a professor from Gothenburg University. Apart of this, there was also a possibility to try out different types of VR-equipment and experiences.

3.4 COMPARATIVE USER STUDY

To learn more about HMD VR in test situations and in particular its suitability for UX tests, a user study was performed. In this study, the currently tested setup of VR (CTS VR) was compared to both the currently tested setup of the driving simulator (CTS Simulator) and a Volvo S90. In all of the tools, a CSD interface corresponding to the latest version available on the market was used. The aim was to investigate how CTS VR compares to other tools when it comes to UX evaluations of digital interfaces and what possible improvements that could be made to make VR better able to cater for experiences of interactive systems. Qualitative as well as quantitative data was collected through interviews and questionnaires. The study was partly confirmative and partly investigative, and the aim was to collect data and give answers regarding the following questions.

- Do VR have a higher level of presence than a driving simulator?
- How important is the accuracy of the hand tracking?
- How does the studied version of HMD VR perform when evaluating UX of in-car interactive systems?
- What points of improvements for the next phase of development could be identified?

PARTICIPANTS

The recruited participants were VCC employees working in departments not directly involved in the development of the digital in-car interfaces.

To obtain coherency, all invited participants had the same native language. This was decided in order to make the tests sessions, including the responses, as comparable as possible. Furthermore, it was done to allow participants to express themselves more elaborately. Due to practical circumstances, Swedish was chosen during the study and therefore it was necessary to translate some of the content.

TEST PROCEDURE

Each test was carried out during 1,5 – 2h according to the procedure shown in the list below. The complete script, including interview questions, is found in Appendix 1.

1. Intro. The participants were informed about the purpose and conditions of the test and what was expected from them. A short interview was also conducted to map their profile.
2. CTS VR test session. The participants completed a number predefined tasks in the VR car.
3. Questionnaires and interview, focusing on presence, immersion, UX and general experiences of the tested tool.
4. S90 test session. Participants drove a predefined route while performing a number of tasks.
5. Questionnaire and short interview, focusing on UX and general experiences of the tested tool.
6. CTS Simulator test session. The participants completed a number of predefined tasks in the Simulator.
7. Questionnaires and interview, focusing on presence, immersion, UX and general experiences of the tested tool.
8. Summarizing questionnaire and interview.

The order of step 2 and 6 was altered for half of the participants.

COLLECTION OF DATA

All test sessions, including the interviews, were recorded using GoPro cameras. The purpose was to be able to listen to the participants again, but also to save the material for later analysis by VCC. Notes were taken by the test leader during interviews and all questionnaires were stored for later analysis.

TEST CONTENT

During all test sessions, the participants were asked to execute a number of predefined tasks. Instructions were given continuously by the test leader sitting in the passenger seat during each test session. The tasks are summarised in table 1. To make the different test methods comparable the tasks were chosen to be as similar as possible. However, due to limitations of the equipment the test sequence and tasks were not identical which can be found in the table. Sequence of tasks tested in CTS VR was repeated once to ensure the duration of the different tests become as similar as possible.

Table 1. The included tasks in the three tested tools

CTS VR test session	S90 test session	CTS Simulator test session
Ensure seat belt is fastened visually in DIM	Fasten seat belt and adjust seating position	Adjust seating position
Set a destination	Set destination	Set destination
Start driving by activating the left turn indicator	Leave the parking lot and start driving	Activate left turn indicator and start driving
Make a phone call	Make a phone call	Find contact in address book
End phone call	End phone call	-
Activate 360 degrees camera	Activate 360 degrees camera	-
Park the car by activating the right turn indicator	Park the car in reserved parking spot	Activate right turn indicator and stop the car along the road
(Repeat the sequence once)	-	Check the weather forecast for the upcoming days

INTERVIEWS

In connection to the introduction of the study where the participants were informed about what they were going to do, a short introductory interview was performed. The purpose was to map the profile of the participants, foremost regarding experience of VR equipment and the CSD concept that was going to be tested during the study.

All test sessions were followed by a semi-structured interview to get a deeper understanding for how the different test methods were experienced by the participants but also to elicit data about how they talked about the concepts tested from a UX perspective.

The interviews together covered almost 40 minutes of each study. Notes were taken by the test leader, but were complemented afterwards when listening to the recordings one more time. The interview questions were chosen to generate answers to the Questions at issue presented in the introduction of this report but also to the more specific ones for the study, introduced in the beginning of section 3.4 Comparative User Study. The full manuscript for the interviews can be found in Appendix 1.

In the end of the study a summarizing interview was conducted to let the participants reflect upon differences and similarities between VR and Simulator.

QUESTIONNAIRES

The study contained three different questionnaires, two standardized ones and one custom made. The standardized ones were chosen in order to make the data comparable to other studies. The three questionnaires are described in the following three paragraphs.

All three test sessions were followed by the User Experience Questionnaire (UEQ) (Laugwitz, Held & Schrepp, 2008) where the participants were asked to rate the experienced CSD concepts based on 26 different scales with contrasting attributes. The scales used are shown in Appendix 2. Since the concepts in the different test mediums were almost the same with only minor differences, the purpose of the UX questionnaire was to expose differences in how participants rated the concepts depending on which test tool that was used. The participants were asked to complete the questionnaire rather quick and spontaneously to collect data about their initial experience of the concepts.

Apart of the UEQ questionnaire, the test sessions in CTS VR and CTS Simulator were also followed by the standardised questionnaire ICT-SOPI (Lessiter et al., 2001) which concerns the topics presence and immersion. The reason for not including this questionnaire in the S90 test was that the level of presence and immersion were considered at its maximum in real car testing. The original questionnaire consists of 44 questions were the respondent is supposed to grade how much they agree with different statements, on a scale ranging from one to six. In this project 12 of the statements were considered relevant and therefore the other ones were discarded. In addition to this, two custom made questions were added in order to make the questionnaire better adapted to the questions at issue. Due to copyright reasons, the questionnaire template is not included in this report.

When all test sessions, including the interviews, were finished the participants had to answer a summarising questionnaire. The questionnaire consisted of three questions where the respondent was asked to choose between CTS VR and CTS Simulator, see Appendix 3.

ANALYSIS OF THE COLLECTED DATA

The answers from the questionnaires were registered into Excel files to facilitate processing of data. The UEQ was analysed using an Excel template created by the developers of the method. The analysis of the data from ICT-SOPI was supported by guidelines for how to calculate the responses. Through this it was possible to analyse it and to find patterns that could later be used in the project. The focus of the analysis was the differences between CTS VR and CTS Simulator since that would clearly indicate where the two tools have their strengths and weaknesses, and thereby where the greatest potential improvements could be made.

All interviews were listened to one more time and the notes taken during the interviews were complemented. The notes from the different participants were compared to find patterns of subjects and topics frequently discussed. Special attention was taken to how the participants were talking about the concept depending on what medium they had tried.

3.5 IN-DEPTH INTERVIEWS

After finishing the Comparative User Study, which aimed to identify factors that are important for test participants, the next step was to identify needs among DUX department employees that will make use of the VR rig.

Therefore, these users were mapped, and thereafter in-depth interviews were performed with them. In total, five such interviews were performed and the persons who participated were the following; one technician responsible for the VR-rig, two test operators working with conducting of user studies concerning UX and usability, one concept leader ordering user studies, and lastly one project leader at the IT department's innovation team working with development of VR and AR. The interviews had a semi-structured format and were based on the questions shown in Appendix 4.

Apart of identifying needs among these stakeholders another purpose with the in-depth interviews was to get a better understanding for VCC's goals and plans within the VR-field.

During all the interviews audio recordings were made in order to enabled them to be listened through afterwards. This in turn made it possible to process the information more thoroughly.

3.6 IDEATION AND CONCEPT DEVELOPMENT

After the data collection phases, all data was analysed and concretized into actual needs of the different user groups involved in the VR rig. The purpose was primarily to get a better overview in order to facilitate the creation of concepts. Based on the insights gained and the conclusions drawn a concept development process was initiated. The main stages of this process are described in the following paragraphs.

IDEATION

With the analysed data as a basis, ideation was initiated. The first step was to ideate separately on each of the identified user needs in order to create a large number of partial, or freestanding, ideas. These ideas were thereafter combined and developed further into three different concepts, corresponding to different design directions on a principal level. This was done through a methodology inspired by Morphological matrix. Storyboards (Martin and Hanington 2012) showing possible scenarios, were used to communicate how the concepts were to be used.

CONCEPT EVALUATION

All three concepts had potential of fulfilling the user needs identified during the in-depth interviews, but in different ways and to different extent. An evaluation was done heuristically by the authors and were based on listing the strengths and weaknesses for each concept. This was done based on two conflicting factors that were identified as the most significant ones. As a result of the evaluation, one of the design directions was selected for further development.

FINALIZATION

Finally, the selected design direction was to be transformed into a more tangible concept. In order to obtain as good result as possible, some inspiration was also taken from the other concepts. The final concept was described and visualized by using CAD programs.

3.7 CREATION OF GUIDELINES

Guidelines were formulated to describe how the VR technology should be used in the automotive context when the aim is to evaluate UX of digital user interfaces in the vehicle cockpit. The guidelines were based on theory, observations and data collected throughout the project. The guidelines cover how to work and develop the actual VR rig but also how to act in test situations.

04 COMPARED TOOLS

This chapter will give an overview of the tools that were used in the Comparative User Study, including what they consist of and how they are used.

4.1 CTS VR

The currently tested setup of VR (CTS VR) was constructed for demonstrating UX of in-car interactive systems. It consists of a HMD headset, a physical rig, and custom made virtual content enabling users to experience driving scenarios from a car compartment. However, the scenarios do not include full driving possibilities like a driving simulator. At the time when the project was performed the system was still under development, and it had not yet been used for any official user studies. Therefore, the studies performed as part of this project were the first where the system was used for UX evaluation purposes.

THE HEADSET

The VR equipment which is part of CTS VR is a HMD system. Another device that is used together with the system is an IR-based hand tracking camera which is attached on the front of the headset. This camera gives the system a possibility to track users' hands which could thereafter be visualised in real time inside of the virtual environment. A headset, covering only one of the ears are included in the setup, however there is no sound included in the scenarios.

THE PHYSICAL RIG

The rig used in CTS VR is shown in figure 4. It is built on a metal frame holding a driver's seat, a passenger seat, a steering wheel, and a dashboard made of cardboard. On the dashboard, a sheet of plexiglas is attached as a representation for the CSD.

The CSD is equipped with capacitive sensors which allows it to register haptic interaction. It works as one big actuator meaning that it cannot register locations in the interaction but only has two states. The idea with this was to enable events in the scenarios to be triggered by touching the CSD. However, the technology was not experienced as completely reliable and therefore there was also a possibility to trigger the events from the computer running the application, using a Wizard-of-Oz principle.

THE VIRTUAL CONTENT

As mentioned earlier, the virtual content used in CTS VR enables test participants to experience a driving scenario from a car compartment, corresponding to the interior of an existing S90. The tasks included in the scenario are shown in the following list.

1. Ensure seat belt is fastened visually in DIM
2. Set destination via touch
3. Start driving by activating the left turn indicator
4. Make a phone call via touch
5. End phone call
6. Activate 360 degrees camera
7. Park the car by activating the right turn indicator

Figure 4. The VR rig which is part of CTS VR.

4.2 CTS SIMULATOR

The simulator used in this project, referred to as CTS Simulator, is shown in figure 5. Its primary use area is usability testing but sometimes UX tests are also conducted there. The simulator is of a fixed base type, surrounded by projector screens spanning around 180°. The base itself consists of a stripped off front part of a chassis, holding a driver's seat and a passenger seat. Furthermore, a sound system of the same type that are usually used for desktop computers are integrated in the chassis. The setup enables participants to handle the driving simulator in the same way as a real car through its implemented steering wheel, pedals and gear shifter. Apart of these components, it is also possible to incorporate a working DIM and CSD.

Besides the physical part of the CTS Simulator, it also includes a large number of scenarios taking place in different environments. Two other non-physical parts are the digital content used in the DIM and the CSD. For both these parts there is a possibility to test digital user interface concepts easily since the two parts simply work as displays connected to a control computer.

Figure 5. CTS Simulator including the physical parts as well as the surrounding virtual environment.

05 VR OUTSIDE OF DUX

This chapter will present VR-tools that were observed during the explorative study, both internally at VCC and externally.

5.1 HMD VR AT VISUAL ARENA LINDHOLMEN

The external actor Visual Arena at Lindholmen primarily uses HMD VR as a communication tool during different kind of events and its main purpose is to act as a neutral platform for companies and students interested in VR.

The studio, that was mainly used for presentations during events, was equipped with an HTC Vive headset. Two standard lighthouses were mounted to the walls and standard HTC hand tracking controls were connected to the setup. The technician demonstrated material from Stadsbyggnadskontoret describing how the district of Lindholmen will look in the future. To look down on the streets from the roof of the highest building was experienced as quite scary, indicating a high level of presence and immersion. It was possible to walk around in the virtual environment but haptic interaction was not included in the presented material and therefore no hand tracking controls were used.

The technician considered the high level of engagement as one of the most important advantages of VR. However limited visual quality and the fact that many of the visitors experienced simulation sickness was considered as important disadvantages. The technician mentioned that the headset in the near future will probably be possible to connect wirelessly to the computer instead of using wires that limits the possibility to move. He also pointed out the importance of placing the headset in the right position to obtain best possible visual quality.

In the office located next the studio, Oculus Rift headsets were used for different student projects. During the visit, the headset and its belonging handheld controllers were demonstrated by some of the students. When it came to the controllers, they offered an accurate tracking of the hands but the controls themselves were experienced as clumsy and did not offer a realistic feeling when interacting.

5.2 CAVE SYSTEM AT THE ERGONOMICS DEPARTMENT

One of the ways in which VCC uses VR is through a CAVE system situated in the Ergonomics department. The system consists of a room where projections are made on three walls and the ceiling, and in the middle of the room a driver's seat is placed. The CAVE measured roughly three times three meters with a height of two meters. By using passive 3D glasses equipped with tracking points, users can experience a 3D version of a car interior and exterior in 4K resolution. The virtual content fills the space around the driver seat so that it surrounds the user, in a similar style as a hologram.

The primary use area for the CAVE as a whole was, according to the technician responsible for it, to test ergonomic aspects regarding how the car is experienced from the inside of it, such as the driver's view or the space for passengers. The CAVE is seen as a complement to other tools since it is not the best choice for all types of tests. For example, some tests require the possibility to interact with physical objects and then physical models are more suitable. An example of such a situation could be when evaluating how it is to step in or out of a car.

5.3 HMD VR AT THE DESIGN DEPARTMENT

One of the departments at VCC that uses HMD VR is the Design department. The work is still in an early phase, and therefore they have primarily invested in it to explore the way of working. This enables them to visualise and experience full scale models of cars with a high fidelity. The primary use area today is assessments and evaluations of visual aspects, ranging from material choices to surface design. The experience does not include any tests of haptic interaction nor any driving possibilities. Due to these reasons, the experience does not require any other physical parts than a computer and a headset including its tracking system.

06 FINDINGS FROM THE COMPARATIVE USER STUDY

This chapter will present the findings from the Comparative User Study. First an overview of the main result will be given. The next part is then organized according to factors considered to have significant impact on how CTS VR was experienced.

6.1 OVERVIEW

All participants seemed to be in a positive mood and quite enthusiastic when they arrived to the test. Most of them had been involved in user studies at VCC before and some had also tried the CTS Simulator earlier. No one had been part of a study involving VR, however some participants had tried an early version of the CTS VR at a fair displaying new technologies at VCC.

Of the 13 test participants, 5 were women and the ages ranged from 26 to 61. The big majority owned a car from Volvo and drove on a regular basis, but none of them had a car equipped with the latest CSD interface that was tested in the study. However, since all participants were Volvo employees most of them had tried out the new interfaces when they used cars for other job purposes.

In all test tools the participants first tried to adjust seating position and fasten the seat belt like they were sitting in a real car. However, the CTS Simulator was only equipped with a non-functional seat belt which could not be pulled out or fastened. CTS VR had an icon indicating belt in the DIM but did not have a physical belt at all, neither any possibilities for adjusting the seating.

Generally, participants talked about the driving dynamics in both CTS VR and CTS Simulator. In none of the tested tools participants experienced that the cars behaved like a real car. It also caused different levels of simulation sickness among many participants, a known factor of driving simulators (Thattacherry, 2000), which was not the case for CTS VR.

In CTS VR, it was observed that several participants changed their driving behaviour. Generally, people spend more time looking at the CSD like if they did not feel the same responsibility as a driver. One group behaved like passengers while another group reacted instinctively to what happened in the virtual surrounding. A common behaviour was to bend forward towards the CSD to better see the interface due to the low resolution in CTS VR.

The quality and accuracy of the hand tracking technology that was used in CTS VR varied a lot and caused problems for the participants. The tracking was especially bad when grabbing the steering wheel or interacting in the periphery. The participants were apparently annoyed about this fact and it heavily affected the interaction. The fact that the physical rig did not fully correspond to the virtual coupé, which resulted in participants missing the physical plexiglas CSD, was also a contributing factor to difficulties of interacting with the in-car systems.

The result from the UX evaluation questionnaire (UEQ) showed similar result for CTS Simulator and the S90. However, the results from the CTS VR were lower in all aspects even though the interfaces and tasks were similar in all test tools. The questionnaire regarding presence and immersion (ITC-SOPI) showed more positive results. Here CTS VR showed the lowest level of negative effects, and furthermore it was ranked equal as CTS Simulator when it came to the level of engagement. However, the most positive data was elicited from the interviews. Here participants in general had a positive attitude towards the use of VR technology in user studies and they believed in its potential.

6.2 INSIGHTS

The following paragraphs will contain deeper analyses from the Comparative User Study. The result from the interviews and questionnaires will be presented together with observations made during the study. The findings will be organized according to factors considered as important to take into account when developing a new VR-rig based on the limiting factors of CTS VR (due to technological and project scope boundaries of the tested setup).

THE RESOLUTION IN CTS VR WAS NOT SUFFICIENT

During the observations and interviews, resolution was identified as too low which caused several problems like blurry texts and icons in the CSD interface, primarily for small details. All 13 participants complained about difficulties when trying to read the content and it was therefore seen as a major problem. These problems were not related to the design of the CSD interface, but solely to limitations with the available VR technology of today.

"Oh, it was really hard to see, it was extremely blurry" (Participant 11)

One of the consequences of the low resolution was that many participants experienced the interaction with the CSD as difficult. Because of this, some of them got irritated during the test, and some expressed that they though it did not allow them to evaluate the concept in a fair way. When it came to the irritation, the conclusion drawn was that moods in general may affect the rating of a tested concept even if it is not actually caused by the concept itself, but by the test tool. Regarding the sense of not being able to evaluate concepts fairly, indications to this was given by the qualitative data exemplified in the following quotation.

"It doesn't feel fair to assess the system when it looks this blurry" (Participant 3)

The changed driving behaviour were another consequence of the low resolution. Participants changed their driving position in order to see the content of the CSD more clearly. More in detail they bent forward towards the CSD to come closer to it, resulting in an unnatural driving posture as seen in figure 6. Furthermore, the low resolution generally made the participants spend more time on exploring the interface before and during the interaction with it, which also contributed negatively to how well they kept track of the traffic situation.

"It feels like I'm not focused on the road, since I cannot see the content of the CSD clearly" (Participant 5)

THE HAND TRACKING WAS NOT ACCURATE ENOUGH

The overall quality of the IR-based hand tracking was low even though the hands sometimes were quite synced in terms of location. As shown in figure 7, data from the presence and immersion questionnaire showed that participants thought it was more natural to interact with the in-car system using their hands in the CTS Simulator.

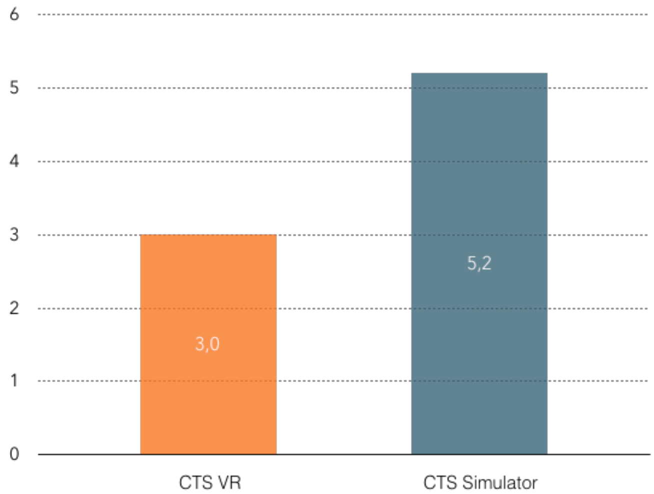


Figure 7. Responses, showing the average value, regarding where participants experienced it as natural to interact with the in-car system using his/her hands. The scale goes from 0 (not natural at all) to 6 (completely natural).

When the hands were held in front of the headset the accuracy of the tracking was acceptable but when grabbing the steering wheel the hands often acted strange. For example, at times the users' fingers were shaking and the hands were placed in wrong positions.

Figure 6. Image showing how participants bent forward during the test.

This phenomenon was expected since the hand tracking camera that was mounted on the headset could only estimate the movement on the front side of the steering wheel. Interactions made in the periphery generated the same kind of problems, like strange directions of the hands or hands that completely disappeared.

"The hands are sometimes really good and sometimes really bad" (Participant 12)

This issues heavily affected the participants and from interviews the hand tracking was identified as key issue that heavily affected the experience. Through observations it was also clear that many participants spend more time looking at the CSD than what could be considered as appropriate.

"It was hard to know exactly where you touched the screen. (...) If it registered my intensions right" (Participant 10)

THE LEVEL OF VISUAL DETAILS DID NOT SEEM TO HAVE SIGNIFICANT IMPACT

In both the VR test and the simulator test, many participants talked about differences regarding visual aspects in the two virtual environments. The overall opinion was that the environment in CTS VR was seen as simple compared to CTS Simulator. Furthermore, people seemed to be more positive to the environment in CTS Simulator which was for example supported by the fact that participants described the graphics of the traffic environment in VR with words such as *"boring"* and *"unfinished"*. Also in the questionnaires, it was shown that the environments were experienced differently in the different test tools as shown in figure 8. The environment in CTS VR was ranked as less natural than CTS Simulator.

Despite these results, the main conclusion drawn was that the level of visual detail of the traffic environment was not a significant factor when it came to the overall experience for the test participants.

One example of this was that many participants reacted strongly to events in the environment, like oncoming traffic when leaving the parking lot or a motorcycle showing up in an intersection. A few participants reacted instinctively and tried to avoid collision by turning the

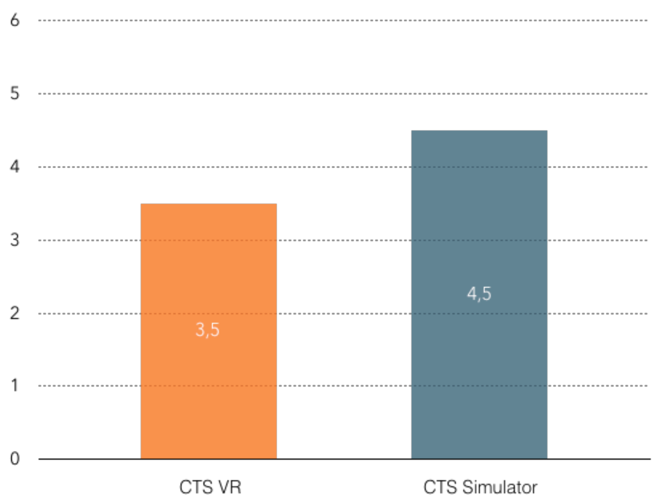


Figure 8. Diagram showing the average values from the ITC-SOPI questionnaire regarding ecological validity. The scale goes from 0 (not valid at all) to 6 (completely valid).

steering wheel which they were asked not to do because of technical reasons. From the quantitative data, it was also clear that participants felt more drawn in when testing CTS VR compared to CTS Simulator despite negative opinions about the level of visual details in the traffic environment.

Another positive aspect related to the virtual environment was that participants described CTS VR as a more coherent experience than CTS Simulator. The main reason was that the compartment and the surrounding environment were represented in the same way there, but in the simulator it was rather experienced as two separated parts; one physical and one virtual. Furthermore the interior in CTS Simulator was considered as more rough and unfinished than in CTS VR; for example since it consisted of visible wires and other electronic equipment. Since the compartment in CTS VR was virtual this was avoided.

"The VR was like a whole, the simulator was more like two different parts" (Participant 1)

One third argument for that the level of visual detail was not significant was that most people spontaneously put it in relation to the driving dynamics and the possibility to handle the car. The quotations below exemplifies how some of the participants valued the two aspects.

"The graphic is partly influencing the overall experience, but I also believe that the fact that I'm not driving the car myself affects as well. I don't need to actively steer the car. The driving probably correspond to 70% of the influence" (Participant 10).

"I think having a connection with the steering wheel is more important than the environment" (Participant 13)

THE ABILITY TO DRIVE YOURSELF INCREASES THE REALISM SIGNIFICANTLY

One of the most affecting issues identified during the study was the fact that the participants did not drive the car themselves in CTS VR. The participants were asked to follow the traffic and imaging they were driving but at the same time they were asked not to turn the steering wheel because of hardware reasons. Despite this, data from the presence and immersion questionnaire, shown in figure 9, indicates the same level of engagement in both CTS VR and CTS Simulator.

"If I had been steering myself I would have been very engaged" (Participant 12)

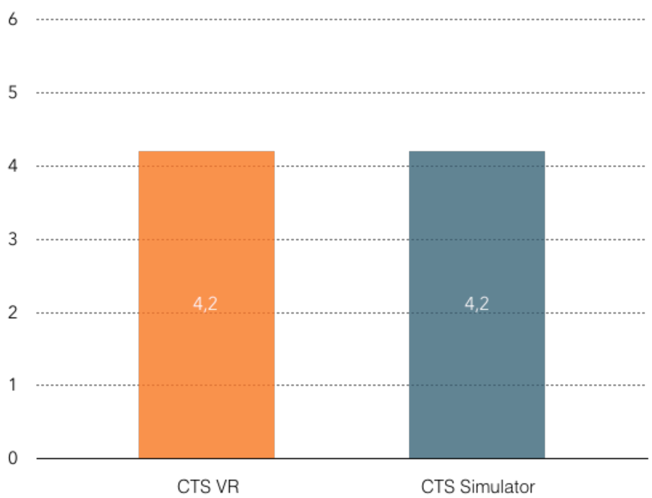


Figure 9. Diagram showing the average values from the ITC-SOPI questionnaire regarding engagement. The scale goes from 0 (not engaging at all) to 6 (completely engaging).

The lack of control of the driving heavily affected the behaviour of the participants. Some described it like they were passengers in the car even though they were sitting in the driver seat. A few seemed to believe they tested an autonomous driving concept which they did not. In combination with the low visual resolution this made participants spend much more time looking at the CSD then what could be considered as responsible driving behaviour.

"I focused even more on the touch screen than I focused on the driving" (Participant 1)

"If you cannot steer, the sense of being in a car is almost gone" (Participant 3)

"I feel like I'm a passenger" (Participant 8)

Some participants became very immersed and instinctively used the steering wheel to avoid collision even though they were told not to use it as earlier mentioned. During the interviews, participants discussed the absence of pedals for braking and acceleration. Some participants reacting to the motorcycle also tried to use the non-existing pedals to stop the car.

"When the motorcycle appeared, I pressed the brake pedal in the floor" (even though there were no pedals). (Participant 12).

THE DRIVING DYNAMICS IN CTS VR IS SUFFICIENT

It is important to consider the driving dynamics since it could cause nausea and dizziness. The feeling of dizziness and nausea could be considered problematic when evaluating UX since it just like irritation can cause less reliable test results.

The most common way in which participants described the driving dynamics in CTS VR was by using similes to things like; riding on a railway, riding a treadmill or being in a computer game. Furthermore, the movement patterns were described as a bit edgy and rough. Neither CTS Simulator was experienced as completely natural and furthermore nausea was identified among some participants during the simulator session.

The difference regarding how participants experienced the driving dynamics in the two test sessions were also noticed when analysing the ITC-SOPI questionnaire. Here the questions regarding nausea, dizziness, and disorientation were combined into one mean value called negative effects. The result from this is shown in figure 10.

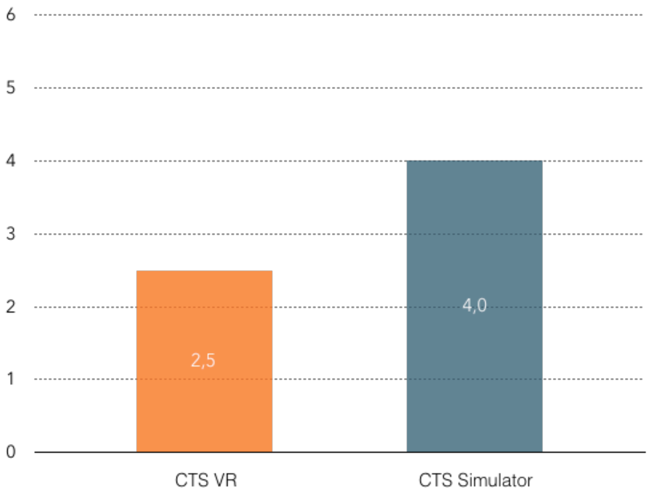


Figure 10. Diagram showing the average values from the ITC-SOPI questionnaire regarding negative effects, which is a combination of the level of dizziness, nausea and disorientation. The scale goes from 0 (not negative at all) to 6 (highly negative).

THE PHYSICAL PARTS IN CTS VR DID NOT CORRESPOND TO THE VIRTUAL CONTENT

One notation during the study was that the design of the physical rig used in CTS VR did not fully correspond to the virtual content. Another fundamental shortcoming with the rig was that it was not adjustable, making it impossible to test different virtual concepts if they have different dimensions, which was the case in the current version of CTS VR. However, during the comparative user study only one virtual concept was used, but still there was a mismatch between the physical and the virtual content. More in detail two significant mismatches were found.

The first was that the distance between the steering wheel and the instrument panel differed a lot between the physical and the virtual compartment versions. Because of this mismatch it was not possible to calibrate the system so that it matched up with both the steering wheel and the CSD simultaneously. Instead, one of these two parts had to be prioritized during the calibration which in turn created a sensory conflict when interacting with the opposite part.

The second mismatch regarded the position and the angle of the CSD. Here the physical sheet of plexiglas was dislocated along the instrument panel resulting in that participants often pressed the cardboard outside of the plexiglas when interacting with the virtual CSD. This made many of them experience slight confusion since they had a different expectation on the haptic impression. Apart of this displacement, there was also a mismatch when it came to the angle of the plexiglas compared to the virtual CSD. This resulted in a too large distance in one end of it, and with a gradual transition, a too short distance in the opposite part, as illustrated in figure 11.

"The problem was first and foremost the distance to the screen and the dimensions of the sheet of glass" (Participant 1)

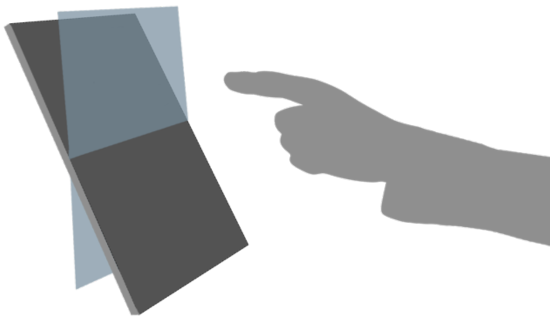


Figure 11. Illustration explaining the mismatch between the virtual CSD and its physical representation.

CALIBRATION OF CTS VR WAS COMPLICATED

To calibrate the virtual content correctly according to the physical rig was impossible as mentioned in the previous section. In addition to this, the calibration process was very time consuming and far from intuitive. The starting position of the camera was placed underneath the car pointing backwards. The methodology for placing the camera in driver position involved pressing multiple buttons on the keyboard without any logical meaning. Moreover, the movements when changing the camera position were very slow.

PARTICIPANTS EXPERIENCED HIGH LEVEL OF PRESENCE AND IMMERSION IN CTS VR

In literature VR is considered to offer a high level of presence and immersion. This was also shown in the Comparative User Study. When it comes to presence, the simulator was ranked slightly higher, as seen in figure 12. The level of immersion on the other hand was higher in CTS VR. This was shown in the summarizing questionnaire that was performed after the participants had finished all the test sessions. When they at this point got to decide if they felt most drawn in in CTS VR or CTS Simulator a majority of the participants choose CTS VR as shown in figure 13.

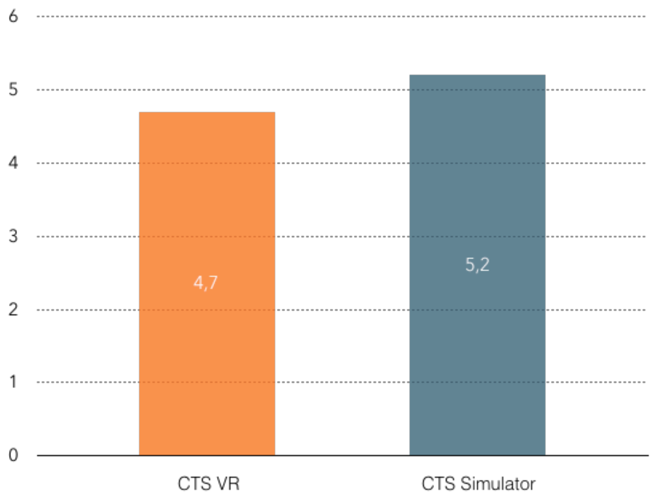


Figure 12. Diagram showing the average values from the ITC-SOPI questionnaire regarding spatial presence. The scale goes from 0 (no sense of presence) to 6 (high sense of presence).

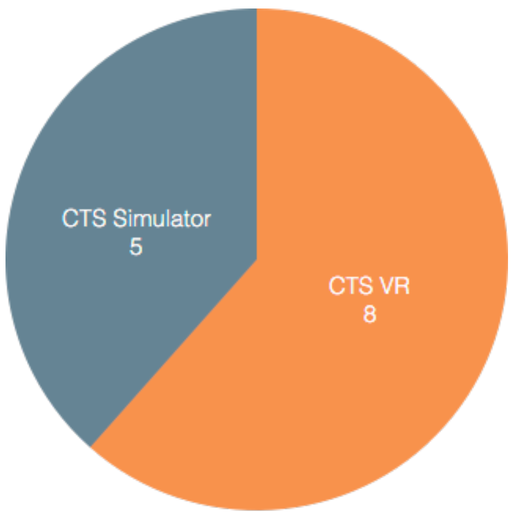


Figure 13. Diagram showing where the largest number of participants felt most drawn in when comparing the two tested tools.

Indications for that CTS VR was more immersive than CTS Simulator could also be seen in the qualitative data. Furthermore, this data also argues for that participants experienced a high level of presence there, even though it was slightly higher in CTS Simulator. The quotations below showcase some of the indications on this.

"Yes, it definitely felt like I was there. It felt like I was in a traffic environment" (Participant 4)

"You experienced it as if you were there, even more than what you did in the simulator" (Participant 1)

"You stepped out of one reality and into another" (Participant 12)

Another way in which it was indicated that CST VR made participants experience a high level of presence was that several of them were immersed to such an extent that they forgot how the real surrounding looked. This was observed several times at the moment when the participants expressed their first thoughts after taking of the headset after the test session.

"Then I came back to reality, saw the grey sheet of cardboard. It was a quite brutal wake up" (Participant 13)

"Was that how the steering wheel looked?" (Participant 6)

CTS VR NEEDS DEVELOPMENT FOR EVALUATING UX

The result from the UX questionnaires (UEQ) showed significant differences in how participants evaluated the CSD concept in the different tools. Figure 14 shows better result for CTS Simulator and the S90 compared to the result for CTS VR which was significantly lower. Since CTS Simulator and the S90 was quite similar, this may be considered a reliable reference level which means that CTS VR needs to be improved. Earlier mentioned aspects such as low resolution and bad hand tracking most likely influences the participants evaluation of the concepts.

In connection to each UX questionnaire the participants also estimated the level of confidence they felt when grading the concept. No significant differences were found, however the result in figure 15 shows less confidence among participants when evaluating the CSD content in CTS VR.

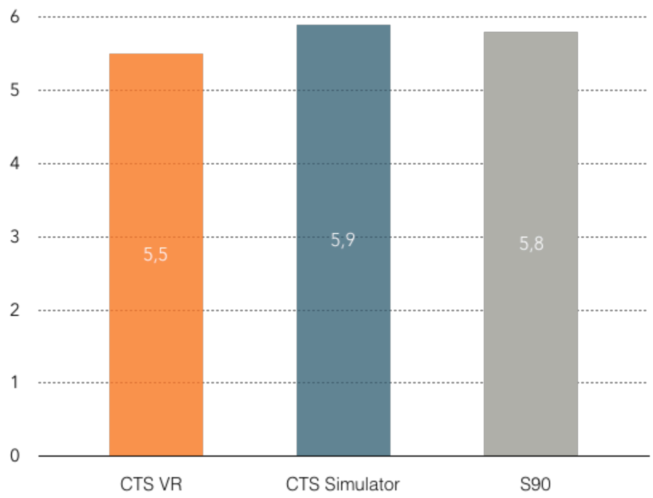


Figure 15. Questionnaire responses showing the average values regarding how confident participants felt when they evaluated concepts in the different formats. The scale goes from 0 (not confident) to 6 (completely confident).

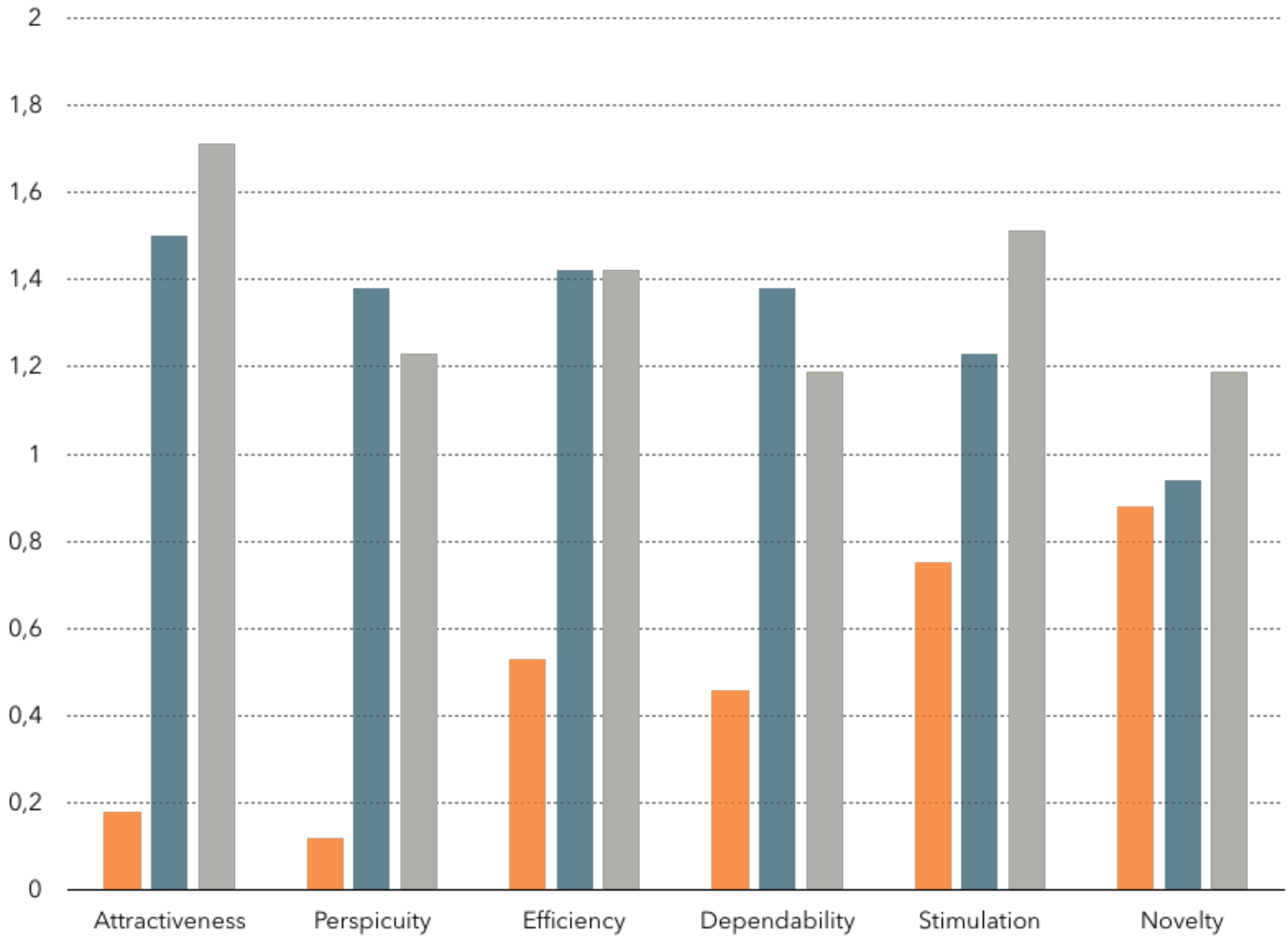


Figure 14. Diagram showing the UEQ questionnaire results collected from the three tools. The scale shows how much the interface fulfills each factor.

6.3 SUMMARY

The study showed that the current version of CTS VR had several shortcomings. One area that was problematic was the VR-equipment which today offered too poor resolution and to unreliable hand tracking. However, these technical problems are expected to be solved in a near future with the evolvement of technology. Another area that was identified as problematic was the design of the physical rig, primarily since it did not match the virtual content and since it was static even though the virtual content was changed. However, making improvements that solves these problems was seen as highly possible.

The main conclusion drawn was that CTS VR as it is today needs development. Compared to CTS Simulator, that has been developed for many years, VR solutions for evaluating UX of in-car interactive systems need development. This was also confirmed in the summarizing questionnaire, which showed that participants preferred to interact with the car in CTS Simulator more than CTS VR as shown in figure 16. In addition to this, almost all of the participant thought that the overall experience that was most similar to a real car was CTS Simulator, see figure 17. However, this could be explained by the fact that the simulator, compared to CTS VR, was built for interactions to a larger extent and thereby included more interaction possibilities.

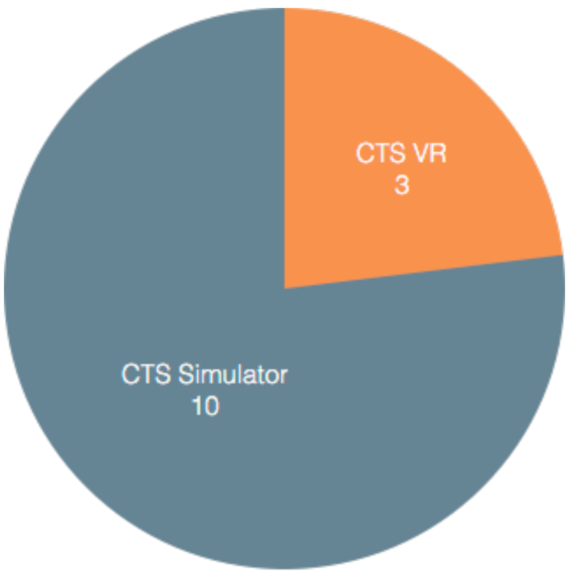


Figure 15. Diagram showing where the largest number of participants preferred to interact with the car.

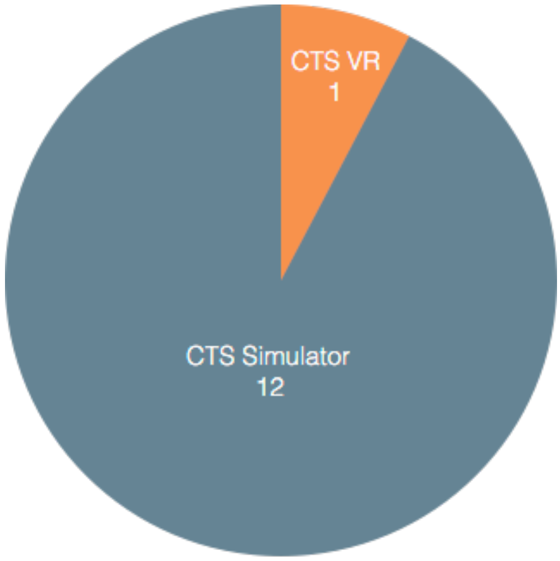


Figure 14. Diagram showing where the largest number of participants thought the experience was most similar to a real car.

Even though a lot of negative aspects were identified, several areas considered to have a great potential were found. First of all CTS VR was experienced as more immersive than the CTS Simulator. The level of engagement was another promising aspect. Already in today's version of CTS VR it was ranked equally as the simulator, but in addition to this many participants expressed that they would have been more engaged if they had to participate more actively in the experience. A third important advantage with CTS VR was that it made participants far less simulation sick than CTS Simulator resulting in a more enjoyable experience.

6.4 DECIDED PROJECT DIRECTION

Due to the findings from the Comparative User Study, together with the insights from earlier stages of the project, it was considered that one of the areas where the greatest improvements could be made was on the physical rig. Due to this it was determined that the forthcoming direction of the project would be to investigate how such a rig should be designed. The next step was therefore to investigate and map the needs and desires among possible users that could be involved in the use of the rig.

07 USERS AND THEIR IDENTIFIED NEEDS

This chapter will present the different stakeholders involved in tests today, and who will be part of tests in future versions of CTS VR. The presentations will focus on the role of each stakeholder group including the needs and desires they will possibly have related to CTS VR. The results are based on the in-depth interviews with VCC employees.

7.1 TEST PARTICIPANTS

One of the key users to consider when designing the rig is the test participant. However, in most tests the participants spend relatively short time in the rig and the focus is therefore to design the rig to be able to collect best possible data. To create an experience where the senses are in congruence is crucial to obtain a true immersive experience. There is an ongoing communication between test participant and test leader in most UX tests, therefore the redesign of the rig should meet this need.

Test participants must be able to:

- See the VE
- See the hands
- Get haptic stimuli from parts where interaction takes place, and that are included in tested tasks (e.g. CSD, turn indicator, steering wheel, pedals, seat belt etc.)
- Communicate with the test leader
- Sit in a driver's position
- Hear sounds from the VE
- Experience congruence between stimulated senses

Test participants should be able to:

- Relate to a story around the test
- Make adjustments on the driving position

7.2 TEST LEADERS AND ASSISTANTS

User studies within UX and usability are led by a test leader who is responsible for the conduction of the test. The main tasks for this person is to inform the users during practical test activities, such as driving or interacting with an interface, and to ensure that the included tasks are performed correctly. The practical test sessions are usually followed by interviews or questionnaires which the test leader is also responsible for.

The most common setup during practical test activities are that the test leader sits in a passenger seat from where he/she gives the instructions to the participant verbally. The extent in which this is done could vary between different types of tests. In UX tests for example, the test leader often tries to have a constant conversation with the participant in order to collect as many of their thoughts as possible. In usability tests on the other hand, it is important to not disturb the participant while performing the tasks since parameters such as efficiency and comprehensibility is often of interest.

Apart of the test leader, UX and usability tests are sometimes supported by a test assistant. The role of this person is primarily to take notes and, if needed, control test equipment.

Test leaders and assistants must be able to:

- Communicate with test participant
- Observe what test participants do (interaction with the virtual UI, driving behaviour etc.)
- Take notes, record audio and record video
- Conduct tests with external participants
- Customize the rig regarding methods and tools used for each test
- Collaborate with at least one colleague
- Move equipment with a car

Test leaders and assistants should be able to:

- Transport equipment by flight
- Collect quantitative data from the rig (e.g. how much the steering wheel is turned)
- Sit down
- Set up, operate, and take down equipment without the need of a technician
- Take part of test participants' experiences

7.3 TECHNICIANS

The technician is the one developing and maintaining the rig, both regarding physical parts and software. All components therefore have to be accessible and adjustable to be easily adapted for different concepts. To minimize the workload of the technician it is desired that the rig and software can be operated independently by test leader and test assistants without support.

Technicians must be able to:

- Adjust the rig and the virtual content so that it corresponds to project leaders' desires
- Access and handle the rig between studies

Technicians should be able to:

- Do changes of the virtual content remotely
- Do quick changes regarding virtual and physical content

7.4 THE COMPANY

The equipment and methodology that are used during user studies could vary largely depending on aspects such as the type of data that should be collected, what concepts that should be tested, or what equipment that should be used. All persons that are involved in decisions regarding this could be grouped into a category of users called the company. More in detail the users could be seen as clients for user studies and for example have roles like project leaders or managers. These persons will not be direct users of the rig, but since they are interested in the data collected by using it, it is crucial to take their needs and desires into consideration as well.

The company must be able to:

- Get test results from different concepts and situations
- Get test results from other user groups than VCC employees
- Access information about the current status of the rig

The company should be able to:

- Get test result from users in remote markets
- Make tests in a time and cost-efficient way
- Communicate a professional impression on test participants (through the rig)

08 CONCEPT DEVELOPMENT

This chapter will present the results from the concept development phase, spanning from the initial ideation activities to the final concept. The first part will explain the starting point of the ideation. Thereafter three concepts, corresponding to different design directions regarding complexity and mobility, will be introduced and thereafter evaluated.

8.1 STARTING POINT

As mentioned in the process chapter, the starting point for the concept development process was to ideate on each of the identified user needs. However, apart of these needs, a number of initial delimitations common for all potential solutions were defined. These delimitations are listed and described below.

THE HAND TRACKING TECHNOLOGY IN ALL CONCEPTS SHOULD BE BASED ON IR-TECHNOLOGY

Accurate hand tracking was seen as important to incorporate. Both due to the insights gained during the comparative user study, but also since theory presented in section 2.3 argued for that representations of body parts could make a VR experience more realistic and reduce the risk for cybersickness. Due to this, it was decided to incorporate a hand tracking camera based on IR-technology which was considered to be the most suitable solution developed so far, even though the technology was criticized during the Comparative User Study. However, in a later stage of the project the accuracy and reliability was improved due to software development, making the technology more interesting again. In addition, an advantage is that it does not limit participants' haptic sense, which for example tracking gloves could do. This feature was seen as important in an automotive interface setting.

ALL CONCEPTS SHOULD ALLOW THE TEST LEADER TO SIT BESIDE THE PARTICIPANT

During the Comparative User Study, it could clearly be seen that the communication between the test leader and the participants worked well when they were positioned besides each other. This was observed in all of the tested tools. The primary reason was that the setting was similar to a natural driving situation where the participant experienced themselves as drivers and the test leader as a passenger.

NO CONCEPT SHOULD HAVE HEADPHONES AS THE PRIMARY AUDIO SOURCE

Based on the fact that many UX and usability tests include close communication between the test leader and the test participant it was decided that headphones should not be used. Solutions where the communication was made via microphones and headsets were discussed but not selected since it was seen as overly complicated in a setting where the test participant sits right beside the test leader. Furthermore, sound with spatial dimensions contributes positively to the experience of virtual environments, as described in section 2.3. However, headphones would make this more difficult to achieve in situations where there is also a need for verbal communication.

ALL CONCEPTS SHOULD BE MOBILE TO SOME EXTENT

One of the main opportunities with the VR-technology is that it requires few physical parts, which in turn enables it to be very mobile. This fact was important to consider when developing the concepts since one goal from VCC's perspective was to facilitate the incorporation of external participants in their user studies.

THE COMPUTATIONAL POWER SHOULD BE INTEGRATED IN THE SOLUTION

To use CTS VR, a computer running the utilized software must be available. During the project, representatives from VCC discussed the possibility to rely on computers on the test site instead of bringing own ones. However, this alternative was not further investigated since it was considered as too unreliable because of factors such as software licenses or operating systems.

IN ALL CONCEPTS, CORRESPONDING PHYSICAL PARTS SHOULD BE AVAILABLE

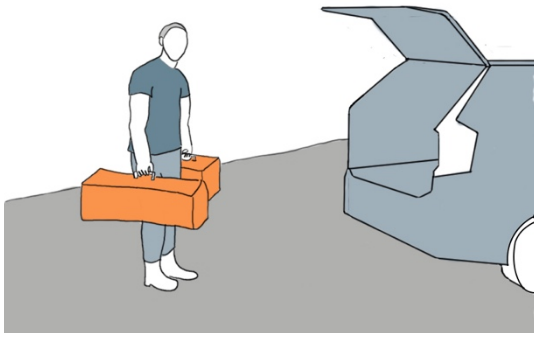
To make the forthcoming concepts comparable to each other, one criteria was to ensure that all of them allowed corresponding physical parts to be used. Therefore it was decided that all concepts should include; a steering wheel, a CSD-representation, a turn indicator, and pedals for acceleration and braking. Apart of these components, it was also specified that the concepts must offer a set of functions including; seating possibilities for the test leader as well as the participant, some kind of desk space for the test leader as well as the test assistant, and solutions that enables all components to be placed at the right position.

8.2 CONCEPT PORTABLE

This concept consists of minimal number of physical parts to make it as mobile as possible. Only parts that are physically touched during tests are included and those are small enough to fit in bags lifted by a test leader or assistant without need of any assistance. Each individual component is free standing and there is no need for a rig that holds the physical parts. Steering wheel, CSD and other physical parts are instead attached to tables and chairs, except the pedals which are placed on the floor. The test site therefore has to offer suitable facilities offering appropriate furnishing, including a chair that acts as a driver seat.

The sound is distributed through speakers placed close to the participants' ears, shaped as a halo mounted to the headset. Chairs and tables for the test leader and test assistants are not included which means furniture from the test site has to be used for this purpose as well. Equipment for recording sound or video are not included and has to be placed on separate stands if needed. Furthermore, a tablet is connected to the computer to enable test leader and test assistants to take part of the virtual content. In figure 18, the concept is presented as a storyboard.

1. Test leader decide what equipment to bring and puts it in custom made bags



2. The bags are then carried to a car and placed in the trunk by the test leader or assistant

3. At the test site, the bags are carried to the location of the test

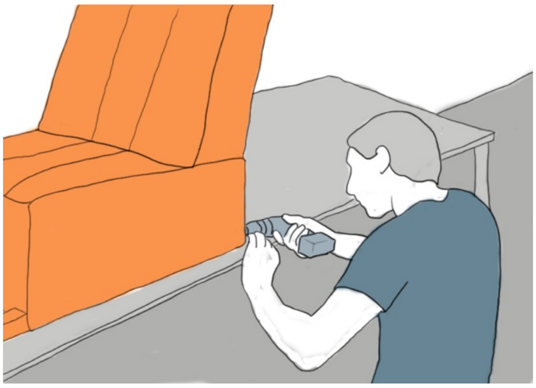
4. Lastly, the equipment is mounted onto suitable furniture and is then calibrated

Figure 16. Storyboard describing Concept Portable in a scenario.

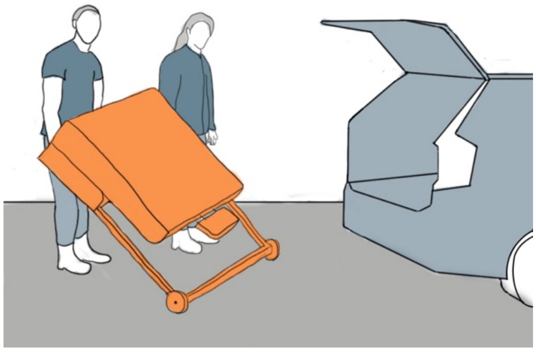
8.3 CONCEPT RELIABLE

In this concept all physical parts, such as steering wheel, pedals, CSD and seat, are integrated into the rig which eliminates the need of appropriate furnishing available in the test site. The core idea is to minimize the number of possible uncertainties by only relying on custom made equipment.

The rig is possible to move into place by two persons. The same persons are then able to unfold and setup the equipment. Speakers for stereo sound are integrated into the rig and so is the equipment for recording audio and video. Foldable chairs and tables for taking notes are brought to the test site. A screen is mounted on the rig that shows the virtual content for the test leader and assistant. In figure 19, the concept is presented as a storyboard.

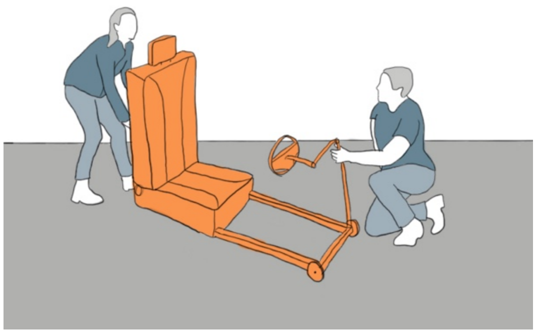


1. A technician customizes the rig for the upcoming study



2. The rig is pushed to the car and placed in the trunk by the test leader and assistant

3. At the test site, the rig is pushed to the location of the test



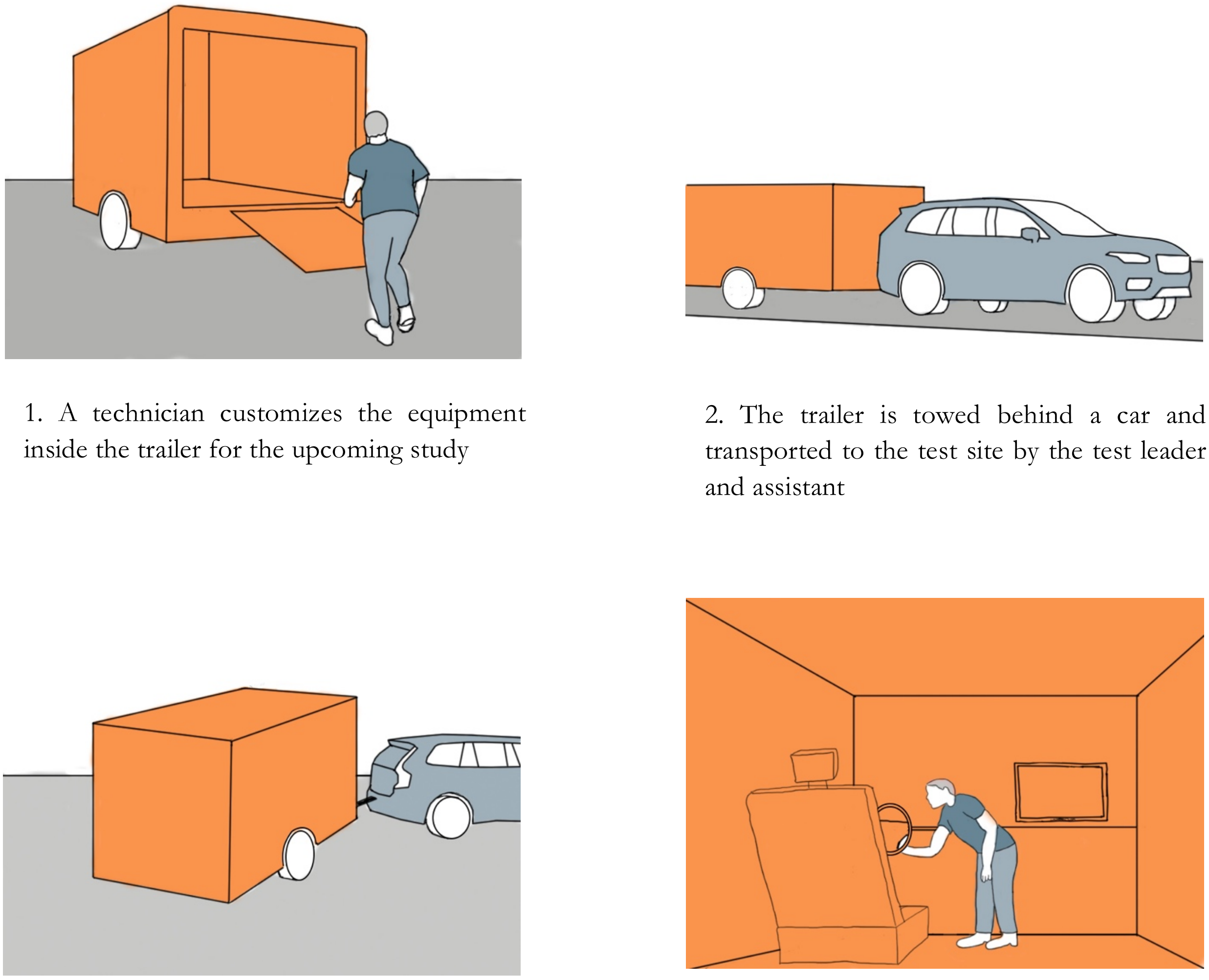
4. Lastly, the rig is unfolded and the equipment is controlled in order to ensure that the calibration is correct

Figure 17. Storyboard describing Concept Reliable in a scenario.

8.4 CONCEPT INDEPENDENT

The third concept consists of a trailer possible to tow behind a car. The core idea is to create a completely independent test studio where all equipment and physical parts are included and ready to be used. Due to this, the only requirement on the test site is that the trailer could be placed. All equipment such as speakers for surround sound and cameras for recording are mounted to the walls inside the trailer.

Furniture such as chairs and tables for test leader and assistants are included in the trailer. So is necessary computers and screens. A big screen is mounted to the wall in front of the test participant to make it possible for everyone in the trailer to experience the virtual content. In figure 20, the concept is presented as a storyboard.



1. A technician customizes the equipment inside the trailer for the upcoming study

2. The trailer is towed behind a car and transported to the test site by the test leader and assistant

3. At the test site, the trailer is parked

4. Lastly, the equipment inside the trailer is controlled in order to ensure that the calibration is correct

Figure 18. Storyboard describing Concept Independent in a scenario.

8.5 EVALUATION

In the process of evaluating which concept to develop further, Concept Reliable was chosen. The two factors *mobility* and *validity* were identified as essential to consider since the evaluation showed that concepts designed for high mobility often results in low validity test results. Moreover, concepts designed for high validity test results usually offers a lower level of mobility since accurate and high quality physical parts requires more physical space than lo-fi versions. Concept Reliable was considered to offer the best comprise between those two parameters. More detailed descriptions of the arguments are described in the following two sections.

VALIDITY

The usefulness of data from user studies rely on the validity of the collected data. In the investigated context two key aspects to consider were identified. The first was to achieve sensory congruence which was shown to highly affect the experience and level of presence and immersion during VR experiences. The second was to be able to obtain the same physical setup in order to ensure that test results are comparable, even if tests are conducted on different sites.

Placement of physical parts could be highly dependent on external factors, such as the type and condition of furniture on the test site. Concept Portable is highly dependent on measurements and shapes of tables and chairs when mounting. Due to this fact, equal and comparable test setups are difficult to achieve. Furthermore the concept is influenced by the stability of the furniture, since if it is not stable enough to stand the weight and interaction with the components, it may risk the validity of the test. Concept Reliable and Concept Independent both include a physical rig which ensures that equal test conditions are possible to recreate, and that a valid result is possible to guarantee. In addition to this, the physical rig offers high stability and robustness and only requires a flat surface to be placed on which eliminates the risk that is associated with external furniture.

The quality of the included physical parts is another factor that could contribute when it comes to achieving congruence between senses. From the Comparative User Study it was indicated that haptic feedback that did not correspond to the expectations of the test participant affected the experience in a negative way. The conclusion was therefore that the criteria for including a specific part is that the haptic feedback is of top quality. If a physical part causes too much incongruity it was considered as better to not include it at all. Concept Portable relies on a seat, representing a driver's seat, that is provided at the test site. However, Concept Reliable and Concept Independent are more comprehensive and have better possibilities to offer high quality haptic feedback.

The sound from the virtual content, as well as the communication between test participants and the test leader, are other factors to consider. Sound from sources placed close to the participant's head could make it complicated for the test leader and assistants to take part of the VR experience, since the spatial perception is lost and the volume is lower. It could also disturb the communication which is an important way to collect data for the test leader and assistants. In Concept Portable, the sound comes from a halo placed around the participant's head which may disturb this communication. While in the other two concepts, where the sound is distributed through speakers, everyone in the room can take part of the sound and nothing is interfering with the communication as long as the sound has a reasonable level.

The possibility to record and save test sessions in a comparable way also affect the validity of tests. A physical rig where voice and video recording equipment are mounted ensures that all tests are recorded and can be evaluated under the same conditions. Both Concept Reliable and Concept Independent offers integrated solutions for recording of audio and video. However, the possibility to achieve high quality recordings is slightly higher in Concept Independent since it offers a more controlled environment. Concept Portable on the other hand does not include these functions which means that it is associated with more uncertainties when it comes to recording of tests.

MOBILITY

An easy way to achieve high mobility is to minimize the number of physical parts. However, during the in-depth interviews it was concluded that this was not necessarily the right way to go in order to meet the user needs. Instead, the key was to make the solution small enough to enable it to be transported by car between test sites. Furthermore, tests are usually carried out for a couple of days, meaning that the need to move it frequently would be low. In addition to this, it was seen as desirable if the solution could be transported by other means of transportation since that would enable an even greater degree of freedom. Based on this argumentation Concept Reliable was seen as the most interesting direction, even though Concept Portable was classified as the most mobile in this respect. Concept Independent is highly mobile when traveling to test sites by car, however when tests are carried out in remote sites it will be time consuming and expensive to bring the trailer.

Another significant aspect that affects the mobility is what each concept requires from the test site, less included physical parts would put higher requirements on the test site. In this respect, Concept Independent would be classified as highly mobile since it basically requires nothing more than a surface to be placed on. On the other hand, it is slightly limited when it comes to indoor test sites since all facilities would not allow a trailer to be placed. Another disadvantage is that the concept would probably still require access to some kind of facility for practical reasons such as getting access to electricity and restrooms. Concept Portable relies even more on what the test site offers. The concept is associated with many uncertainties leading to that it could not benefit from the high level of mobility. Concept Reliable is placed in between the two other concepts in terms of the requirements on the test site. However, compared to Concept Independent, it offers slightly more possibilities in terms of where it could be placed. It would for example be more suitable for indoor use since it could easier be moved through elevators and doors etc.

The ease of setting up the equipment when arriving to a test site was also seen as an important factor to consider. Here Concept Independent has one big advantage; namely that it does not have to be set up. Instead tests could more or less be initiated as soon as the trailer is parked. Furthermore, the need for calibration would virtually be excluded since all the equipment is already mounted. However, it might still be necessary to perform calibrations if the adjustment of the equipment have accidently been changed during the transport. When it comes to Concept Portable, the set-up procedure would be considerably more complicated. Since all the components are freestanding, all of them must be calibrated separately. In addition to this, the possibility to calibrate the set up correctly would be affected by what equipment that is available on the test site. Concept Reliable would also in this case be placed in between the two other concepts in terms of the ease of setting it up. Compared to Concept Portable, it would be easier to calibrate since all parts are already mounted, but less easy to carry to the right place since it is more ungainly.

CONCLUSION OF THE EVALUATION

Concept Portable was seen as the most advantageous concept in many ways in terms of mobility. However, this was considered to be done too much on the expense of the test validity. Apart of this, it was not seen as necessary to strive for maximal mobility based on the identified user needs. Due to these aspect, it was decided that Concept Portable was not to be further developed in this thesis project.

Concept Independent was instead seen as advantageous in many ways in terms of possible test validity. Even though it was closely followed by Concept Reliable, it was still considered as the best choice in this respect. However, it had some significant disadvantages which were; that it could not be transported by any other means of transport than car, that it would be difficult to place in many facilities, and that it would still require some kind of facility for practical reasons. Due to these arguments, the concept was not further developed in this thesis project either.

The winning concept, Concept Reliable, was chosen since it was considered to offer the best balance between mobility and possible test validity. Since all the physical components are part of the same rig, it enables an easy setup of the equipment, low need for calibration, and high possibility to carry out tests in similar ways. In terms of mobility, the concept offered more possibilities than Concept Independent and it was also enough mobile to be used for the same type of studies as Concept Portable.

09 FINAL CONCEPT

With the three concepts and the evaluation in mind, a final concept was developed with the aim of maximizing the mobility without compromising too much on validity.

9.1 OVERVIEW

The final concept, shown in figure 21, is a highly mobile solution which is possible to stow in a car and robust enough to transport by aircraft. The rig is calibrated once for each individual physical concept at VCC in order to obtain accurate precision of the physical elements before it is transported to a test site. Furthermore, the rig is easy to set up by a test leader or assistant without the need of recalibration. In order to give the rig an authentic premium car feeling, it consist of the same materials and surface qualities that are used in VCC's product portfolio.

9.2 INCLUDED PARTS

The concept is made out of three main parts; the body, the arms and the physical elements where interaction takes place. The body and the physical elements are static and not possible to adjust. This means that the arms are the components where all adjustments are made. Below follow more detailed descriptions of the included parts.

BODY

The part that defines the foundation of the concept is the so-called body, which consists of a seat placed on a metal construction, see figure 22. The seat resembles a driver's seat in terms of its shape and surface material and furthermore it puts test participants in a realistic driver's position. The seat is also possible to push forwards or backwards in order to allow a correct driving position regardless of their height. It does not have to fulfil as many requirements as a real car seat, and therefore it is both thinner and lighter in order to support high mobility. Furthermore, the seat is foldable which increases the mobility even more. When it comes to the construction below the seat, it has two main functions apart of holding the seat in a correct position; it acts as storage space for the computer and a hub for all the mounted physical elements.

Figure 20. The part of the VR-rig called the body highlighted in orange.

The storage space primarily contains the computer that runs all the necessary software and the VR-equipment. This was decided due to the fact that the seat in any case has to be elevated in order to become correctly positioned. Furthermore, this placement allows the computer to be protected during transport.

Figure 19. The final concept.

The second function is that it acts as a hub to which the arms could be mounted. This is done on two different attachment points placed on extendible bars, as seen in figure 23. This placement allows the arms themselves to be shorter and thereby they become easier to transport and more effective in terms of material usage.

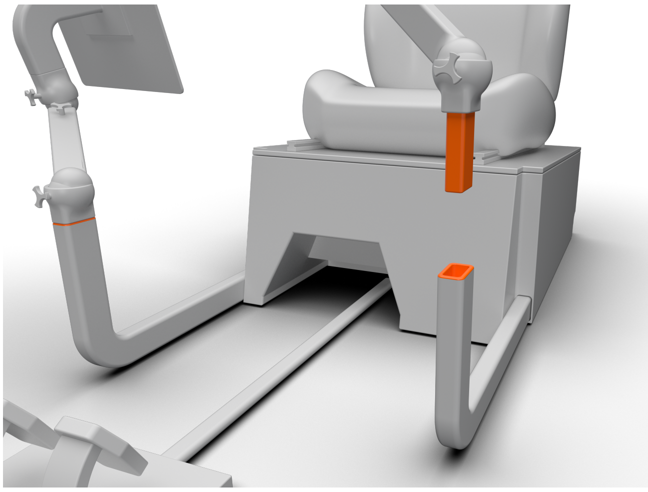


Figure 21. The attachment points where the arms could be mounted highlighted in orange.

On the backside of the driver seat another storage space is available for equipment. This equipment will be further described later in this chapter. The purpose to include storage spaces in the rig is that all equipment is stored together as one unit, to avoid missing parts when performing studies in remote locations.

ARMS

A key part of the concept is the adjustable arms that allows the CDS and the steering wheel to be positioned correctly with a high accuracy. Each arm consists of a telescopic bar equipped with one ball joint and one mounting in each end, as shown in figure 24. All of these adjustment functions are thereafter possible to lock in order to ensure that the high correspondence is kept every time the adjustable arms are connected to the body.

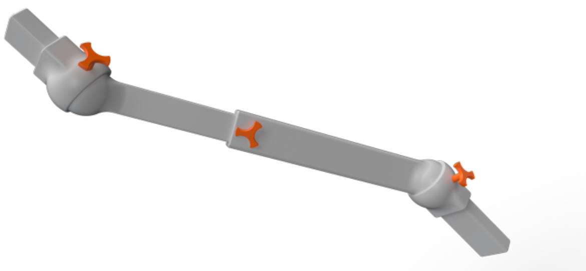


Figure 23. A closer look at an adjustable arm.

If more than one physical configuration is to be tested, one pair of arms is required for each configuration. Due to this, the solution offers more flexibility the more pair of arms that are available. Switching between concepts are done by replacing the set of arms, which is done by simply attaching them using a buckle.

The arms that are currently not used in test, are placed in the storage box on the backside of the driver seat, which was mentioned earlier. The same box is used as storage for the arms during transportation to ensure the correct calibration is not lost.

ATTACHABLE ELEMENTS

The physical elements where the actual interaction takes place, such as steering wheel and CSD, are also possible to store in the box on the backside of the seat. The storage space underneath the seat could also be used for this purpose. All elements have an attachment point to connect them to the adjustable arms. No calibration of the individual components is therefore needed since the arms forces the elements to stay in the correct location and angle.

The physical CSD, which is shown in figure 25, is made out of a large aluminium plate covered by a plastic film to offer the same haptic feedback as a real car. Its dimensions are larger than the existing virtual CSD which enables different kind of virtual CSD concepts to be tested, even if they have different sizes. Since the participant are inside the virtual world, the extra size of the aluminium plate is not visible.

Figure 22. The physical CSD highlighted in orange.

When the steering wheel is mounted onto the adjustable arms no further adjustments are available since the relation between steering wheel and other elements such as the CSD must be fixed. The seat and the pedals are not directly visible in the scenario, and therefore these parts only have to stimulate the haptic sense. Due to this, they are adjustable in order to allow a natural driving position. The pedals are mounted to the middle bar which is possible to fold into the body during transportation. To further enhance the experience the pedals are supposed to offer similar feedback as a real car.

THE VR EQUIPMENT

The VR equipment, such as the headset, is placed in the same storage space as the computer during transportation. A hook is located on the right side of the driver's seat which enables the headset to be hanged safely between test sessions. The headset otherwise risk damages, for example if placed in the seat.

9.3 KEY FUNCTIONS

Altogether the concept offers desirable functionality identified during the project. Some of the most important functions are described below.

ACCURATE ADJUSTMENTS

Due to the many adjustment possibilities of the arms, they could be set to fit virtually any position of the CSD and the steering wheel. This offers a lot of freedom when it comes to testing concepts with different physical configurations which in turn increases the probability for the solution to be relevant in a long-term perspective.

ENSURED SENSORY CONGRUENCE

Due to the stable body, together with the fact that the adjustments of the arms could be locked with a high precision, the concept ensures that high level of sensory congruence could be achieved. By using multiple number of arms, this is possible to achieve even if concepts with different physical configurations are tested.

HIGH MOBILITY

The concept offers high mobility since the bars and seat are possible to fold and since the attachable elements and the arms are possible to detach. While the parts are removed they fit into one of the storage spaces; either the one under the seat or the one behind the backrest. This makes the whole rig small enough to fit in the trunk of a larger car. In addition to this, the rig is also equipped with wheels on one end which allows it to be pushed or pulled in order to increase the mobility even more.

Another aspect that contributes to an increased mobility is that no seats or tables are brought for the test leader and assistant. Instead furniture available on the test site should be used. Despite that it leads to slightly increased uncertainties and that it could affect the comfort for test leaders and assistants, it was decided to go this way since it was considered that the positive effects on mobility outweighed the negative side effects regarding convenience.

EASY SETUP

The fact that the concept is based on a modular system where the hardware is adjusted in advance, combined with the fact that mounting on the test site is done by simply fastening buckles, the setup of the rig becomes easy and time efficient. The easy setup means no technician is needed at the test sites when studies are performed in remote locations, which will reduce cost.

10 GUIDELINES

This chapter is a compilation of recommendations that is supposed to be used as guidance when performing user studies involving HMD VR technology in the automotive industry. The focus is to obtain best possible results when evaluating UX of digital driver interfaces.

ENHANCE THE SENSATION OF BEING IN A REAL CAR

As long as a one-to-one relationship between reality and virtual reality is not reached, it is desirable to enhance the sensation of being in a real car. To succeed with this, one key is to make participants participate more actively in the experience, which for example could be done by implementing driving possibilities, or tasks that require the participants to keep track of the road. Realistic and spatial sound could also enhance the experience. Another key is to make the driving dynamics as realistic as possible. On the way towards this, a preliminary solution would be to minimize the amount of turns and accelerations in order to avoid reminding participants about the driving dynamics.

E.g. Do not include a task where the car leaves a parking lot if the car behaves unrealistically during the turn.

USE SUITABLE NARRATIVES

Narratives and stories are great tools for enhancing the experience for participants. However, if they are included in the wrong way they can create misleading expectations and reduce participants' sense of immersion. Due to this it is important that stories and task instructions correspond to each other without reminding participants about eventual limitations or drawbacks with the technology. Furthermore, it is important that the stories and tasks are presented as if they were given in a real traffic situation, and not as if they were given in a test tool.

E.g. If driving possibilities are not incorporated, formulate a task where the participant has to activate Pilot Assist instead of only asking them to imagine that they are driving.

STRIVE FOR SENSORY CONGRUENCE

One should strive for including realistic stimuli of as many senses as possible to enhance the feeling of presence. This study primarily showed that if a VR experience include haptic interactions, sensory congruence between vision and haptics is absolutely crucial. Tiny differences in angles or positions of components could have a major negative effect on the extent to which participants trust in the experience. Therefore, virtual and physical content must be possible to adjust with high accuracy, in terms of positions and angles.

E.g. If the angle and position of the physical and the virtual CSD do not completely correspond, the participant will get confused

ALLOW DIFFERENT CONCEPTS TO BE TESTED

One key strength with VR is that it allows different concepts to be tested efficiently. However, in order to utilize the full potential when testing concepts that include haptic interaction, it is important that physical components are highly adaptable and flexible.

E.g. Ensure that the physical CSD representations are possible to be mounted steadily and be quickly adapted to the currently tested concept.

ALLOW A NATURAL COMMUNICATION BETWEEN THE TEST LEADER AND PARTICIPANTS

To extract valid data from user studies, communication between participant and test leader must be clear to avoid misunderstandings. To make the participant feel comfortable all people involved in the test should present themselves before the participant enter the virtual environment.

E.g. Do not use headphones since it could disturb the communication between the test leader and participants.

PRIORITIZE HOW VIRTUAL CONTENT BEHAVES INSTEAD OF ITS VISUAL APPEARANCE

When developing the virtual environment, the behavior of the virtual content should be prioritized since today's level of visual realism did not seem to affect the experience in a negative way. Also, the theory showed that highly realistic visual appearance does not necessarily support the evaluation of the tested concepts.

E.g. It is more important to include correct tracking of the virtual hands than the quality of their skin texture.

DO NOT INCLUDE TASKS WERE PARTICIPANTS ARE REMINDED ABOUT THE LIMITATIONS OF THE TECHNOLOGY

When choosing what tasks to include, one should carefully take in to consideration the current limitations of the VR rig and the technology itself. If technology cannot generate a good experience, the level of presence and immersion will be decreased.

E.g. If resolution is too poor, do not include tasks where small icons are supposed to be evaluated.

STRIVE FOR A HIGH PROPORTION OF EXTERNAL PARTICIPANTS IN STUDIES

The end user should be included early in the design process of digital driver interfaces in order to support a user centred design process. To design the physical rig for high mobility is therefore of major importance.

E.g. Enable external participants to participate in concept evaluations in order to better reflect the needs of the end customers.

THE TECHNOLOGY SHOULD BE POSSIBLE TO HANDLE BY THE TEST LEADER AND ASSISTANTS

To enhance flexibility and save costs, the VR rig as well as the technology itself should be possible to handle by the employees who are performing the test. This becomes especially important when performing studies at external test sites.

E.g. If a study is performed in Berlin, a technician should not have to come along just to calibrate the equipment or ensure functionality.

11 DISCUSSION

This chapter will consist of discussions regarding six main topics, either related to the project's methodology or its outcome.

VALIDITY OF THE COMPARATIVE USER STUDY

The appropriateness of comparing CTS VR to both CTS Simulator and a real car can be discussed. All the tools are used for testing digital user interfaces but since HMD VR technology is a relatively new tool to use for this purpose its role is not defined to the same extent as the other more established ones. However, to use well-recognized tools as reference points was considered necessary in order to be able to identify the strengths and weaknesses of CTS VR which in turn could create a better understanding for how VR could fit into a development process.

In the comparative user study, the VR experience was presented in a similar way as the driving simulator. For example, the participants were informed about that they were to experience a driving scenario including similar tasks. Even so, the two tools had several known differences. This might have affected the participants' expectations of the two experiences and thereby how they rated them. Furthermore, the fact that the tools differed regarding the possibility to drive probably highlighted the absence of driving possibilities in CTS VR. This fact could have been a disadvantage in terms of how CTS VR was ranked. On the other hand, it highlighted the importance of incorporating driving possibilities.

Afterwards, when looking back at the study, there are a few factors that should have been changed to create more equal test conditions. The most obvious one would have been to use another scenario in the simulator test session where assisted driving was applied, for example by the Pilot assist function available in the S90. This would have made the experiences of the different tools significantly more equal. However, unfortunately this possibility did not appear during the planning phase of the study.

Furthermore, the differences in what tasks that were performed in the tested tools may also have affected the validity in a negative way. To have equal tasks in all tools would have been ideal especially for the UX questionnaire. However, due to limitations of the available prototypes, completely equal conditions were not possible to achieve. Since the evaluation of the actual screen based content was not the main purpose of the study it may not have affected the result significantly.

Another differentiating factor was the lack of sound in the VR scenario. According to theory in section 2.3 the auditory sense highly affects the level of immersion in virtual experiences. Even though results from the study show equal results regarding immersion for CTS VR and CTS Simulator it is possible that including sound would have increased the level of immersion even more.

The choice to only include VCC employees was primarily done because of practical reasons as earlier mentioned. It probably affected the result to some extent even though their responsibilities were not related to the digital content in the compartment. Most of the participants had used the tested interfaces when driving VCC's cars as part of their work. However, what probably affected the result even more was the fact that several of the participants had been part of user studies in the CTS Simulator before. Some participants had also tried the CTS VR but only at an in-house fair at the company and not as part of a user study. This difference in experience could have influenced the result. Participant who had tried the CTS Simulator before had an idea of what they were going to experience. In CTS VR on the other hand they probably did not know what to expect and the level of excitement was therefore probably higher. It is hard to know exactly how the experience corresponded to their expectations, however because of those identified shortcomings in the CTS VR it is plausible that many participants were somewhat disappointed, which may have influenced how participants judge the experience.

SUITABILITY OF HMD VR IN TESTS WHERE HAPTIC INTERACTION IS REQUIRED

As described in the theory chapter, haptics is one of the most complicated features to incorporate in VR experiences. In addition, several difficulties were also identified during the study. Due to this it was questioned how suitable HMD VR is when testing experiences where haptic interaction is required. This was done due to several reasons.

The first regards the fact that one of the most common argument for why VR is a useful in concept development processes is that it allows switching between different concepts by simply clicking a button. This argument works perfectly fine for the virtual content, but when there should be changes in haptic stimuli, in other words when changing physical content, the argument is not applicable.

Another factor that made us question how suitable HMD VR is for interaction regarded sensory congruence between the visual and haptic sense. Achieving a high level of congruence was seen as crucial in order for haptic interactions in VR to be experienced as realistic. At the same time, it was observed that the requirements for succeeding was very high, and that small mismatches in the accuracy or calibration could affect the whole impression of the experience significantly.

The accuracy of today's available hand tracking technology was another factor related to the level of congruence. To generate accurate positioning of fingers, require accurate scanning of shape and movements which was shown to be difficult to obtain with the technology available on the market at the time of this study.

THE APPLICABILITY OF THE CONCLUSIONS DRAWN DURING THE COMPARATIVE USER STUDY

The initial idea with the comparative user study was to investigate how the VR technology performed compared to driving simulators when it comes to UX evaluations of in-car interactive systems. The reason to why these two tools were chosen was that both of them were considered to have similar potential in terms of what type of experiences they could offer. For example, both tools have potential to include interactive interfaces, to simulate traffic situations, and to surround the user.

When planning and organizing the comparative user study, it was decided that a practical study was to be conducted. In order to make this possible within the thesis project, it was necessary to utilize the currently available tools, which were CTS VR and CTS Simulator, even though there were some known differences between them, and that they originally were built to be used for different purposes. In addition to this, it was known that there could be huge differences between different VR experiences as well as simulator experiences; differences that does not necessarily have to be connected to the formats themselves, but could regard almost anything around them. Due to this realisation, it was decided that the study should focus on identifying where CTS VR had its greatest strengths and weaknesses, which in turn could act as a basis for supporting improvements in future versions of VR rigs.

With those thoughts in mind it was realized that it would not be feasible to conduct a study where the results are completely isolated to the two formats. Due to the same reason, it was also understood that the responses would not be general enough to be applicable for VR or driving simulators in general, but rather on CTS VR and CTS Simulator.

THE IMPORTANCE OF INCORPORATING DRIVING EXPERIENCE

During the Comparative User Study it was noted that several participants expressed that they felt like passengers rather than drivers during the VR test session. One of the main explanations was the version of the equipment used in the study did not offer the possibility to handle the driving, but only moved along a predefined path. Another contributing factor was that many participants experienced the movements as a bit rough and edgy.

In the comparative user study, one of the main topics of investigation was how well CTS VR worked as a tool for evaluating UX of in-car interactive systems during driving situations. However, since the factors mentioned in the previous paragraph seemed to be a key in creating a sense of driving, one possible question to investigate further is how much, and how realistic, driving possibilities that are necessary to incorporate. This question gets even more relevant to ask due to the fact that the automotive industry of today is characterized by trends towards autonomous driving.

On a short-term perspective, we believe that the most logical way to solve this would either be to incorporate driving possibilities, or to incorporate suitable narratives and still not include driving possibilities. In the secondly mentioned alternative, the narratives could for example inform participants about that they will not drive by themselves, but instead describe it as they are going to experience automated driving or driving assistance.

REFLECTIONS ABOUT THE OUTCOME

The final concept of the project was developed with the aim of providing inspiration for how to further develop the VR-rig, therefore the solution is on a conceptual level and lacks details. The concept as it is presented in the report would be possible to implement if desired, however more work has to be done, foremost regarding how it should be constructed.

The guidelines on the other hand should be considered as aspects to aim at in the further development and are therefore applicable in near-time, but also in the long run. However, it may be necessary to update them continuously when new insights are discovered. The technology is constantly being improved which opens up for new possibilities but probably also other aspects that has to be taken into account.

Several of the insights gained during this thesis project were in a later stage of the project incorporated by VCC in one of their parallel studies. These insights resulted in improvements in their VR study according to VCC. Some of the changes were; to include sound, use a suitable scenario that puts all tasks in a context, include a turnable steering wheel, and incorporated a new task where Pilot assist was activated in order to explain why the car drove itself. These actions were seen as strong indications for that our results were valid

Regarding the user needs identified during the study, which are presented in chapter 7, the final concept fulfils all of them. However, it could be discussed to which extent. To answer the question, they have to be specified more in detail and weighted against each other. Within the scope of this thesis this was not done since the solution is on a conceptual level. If the concept is to be developed further the user needs should be defined more in detail.

From a sustainability perspective the VR technology in general, and the final concept in particular, have great potential. Except the actual rig no physical models have to be build, transported or discarded since most changes could be done within the virtual content. When it comes to the final concept, the new rig is smaller and is made out of less material than CTS VR. Since the possibilities to adjust the physical rig only involves the adjustable arms, the number of parts that has be exchanged when testing new physical concepts are also limited, resulting in even more efficient material usage.

THE FUTURE OF VR IN THE AUTOMOTIVE INDUSTRY

VR in the automotive industry seems to have great potential. It enables complex products to be visualised in full scale, and it offers an immersive experience. However, we see two different directions for the development.

Due to the complexity when it comes to implementing haptic stimuli in VR experiences, one of the directions is to develop experiences where this is not included. These experiences should then have more of a showcasing purpose, where visual aspects of interactive in-car systems are evaluated. Still we think that it would enable valuable input about in-car interactive systems to be gained, as long as only visual aspects are evaluated and where the virtual content is not built to be interacted with haptically.

The other direction would be to develop VR into something that is closer to driving simulators. In the comparative user study, several advantages were still seen with the simulator, but many of these were not related to the simulator format per sake. For example, driving possibilities and audio from the virtual environment are already today possible to include in VR experiences and therefore it is already possible to develop VR experiences into something more similar. Furthermore, with the continuous and fast technological development within the VR field, it feels highly relevant to expect that the technology will become better in terms of everything from resolution to tracking accuracy. In addition to this, technological development will most likely allow physical rigs to be more mobile. For example, computational power will become less space requiring and VR headsets will be less ungainly. It is also realistic to expect that external tracking systems will not be required.

The technological development in the VR field will for sure open up a lot of possibilities, but it could also cause problems. When thinking about the technology in a long-term perspective, one almost philosophical question that is relevant to reflect on is; which level of realism is ok to strive for in terms of ethical aspects. As claimed in the theory chapter, the optimal VR experience in terms of UX evaluation validity would be to make the experience as similar to real world experiences as possible. However, this might be in conflict with the claim. For example, if the experience is highly realistic, maybe it would not be ok to expose participants to challenging traffic situations.

12 CONCLUSION

To summarize this report, a conclusion of the project will be presented on the following page.

This thesis project has researched HMD VR and its applicability for evaluating UX of digital driver interfaces. VR technology offers great opportunities for creating immersive and engaging visual experiences. However, if the experience contains haptic interactions, high degree of sensory congruence is crucial to obtain.

The main empirical part of the thesis project was the comparative user study where tests were performed in three tools; a VR rig (CTS VR), a driving simulator (CTS Simulator) and a real car (Volvo S90). This study was complemented by in-depth interviews with VCC employees. The studies indicated that CTS VR, with its current design, needs further development to be employed for in-depth UX and usability evaluation of in-vehicle interactive systems. However, many of the shortcomings were not related to VR technology per sake. Instead, some of the factors identified as important were to implement driving possibilities, sound and relevant narratives. Since these aspects are realistic to include, the VR technology was still considered to have great potential.

Throughout this thesis project, a holistic and user centred approach has been applied. Due to this, the guidelines created were considered to give valuable input to VCC from a new, less technology-based, perspective.

The final concept was a physical VR test rig, able to be transported, which allows user tests outside of VCC to be conducted. The key with the concept is that it offers optimal balance between mobility and possible validity of test results.

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APPENDICES

APPENDIX 1: FULL MANUSCRIPT OF THE COMPARATIVE USER STUDY

INTRODUKTION

Tack för att du deltar i vår studie. Den här studien är en del av ett projekt där vi undersöker hur olika testverktyg kan användas i en designprocess för att utvärdera digitala gränssnitt. Med andra ord ligger fokus på alla skärmar inne i bilen. Du kommer att få testa ett VR-headset och en körsimulator, och varje test kommer att följas av enkäter och en intervju. Efter de två testerna kommer vi ha en kort sammanfattande enkät och intervju.

Nu börjar du med att testa VR/Simulatorn. Den andra utrustningen finns i en annan byggnad och därför kommer du få köra en Volvo S90 vid transporten dit.

Innan vi börjar vill vi bara påminna om att när det handlar om bilkörning är den primära uppgiften alltid att köra och hålla koll på vägen. Den sekundära uppgiften är att interagera med olika system i bilen.

Det är fritt fram att prata under hela testet och det finns inga rätt eller fel svar. Testet kommer att spelas in med hjälp av GoPro kameror, hoppas att det är ok med dig?

(Det kommer hjälpa oss när vi analyserar resultatet och det kommer inte att publiceras offentligt utan ditt medgivande).

Slutligen vill vi även nämna att vissa personer känner av "simulation sickness", vilket liknar åksjuka. Om du känner av detta är det bara att säga till, det är helt ok att avbryta testet när som helst.

INTRODUCERANDE INTERVJUFRÅGOR

Kör du bil regelbundet?

Om ja, vilken bil kör du?

Har du testat VR eller Körsimulator tidigare?

Hur gammal är du?

VR TEST

Du kommer nu att få uppleva en förarplats i VR, dvs en miljö där du sitter i en bil med en ratt och skärmar framför dig. Du kommer att använda det här headsetet och följa instruktioner från testledaren som kommer sitta i passagerarsätet. Se till att headsetet sitter bekvämt och att du har den bästa möjliga bildskärpan.

Innan vi påbörjar körningen får du gärna bekanta dig med bilen i någon minut.

- Vänta i någon minut

Nu kommer vi be dig att utföra ett antal uppgifter. Om någonting är otydligt så är det bara att fråga oss när som helts.

Innan du påbörjar körningen ska vi se till att ditt säkerhetsbälte är fastspänt

- Fäst bältet (görs virtuellt av testoperatören)

Din första uppgift är att ange en destination via touch. Sätt destinationen till Avenyn 4 i Göteborg.

- Ange destination via touch (gör flera tryck på skärmen)

Nu är vi redo att åka. Blinka vänster för att få bilen att börja köra längs gatan.

- Slå på vänster blinkers

Nu ska du ringa ett telefonsamtal till kontakt nummer två i kontaktlistan

- Ring ett telefonsamtal via touch (CSD)

Nu kan du avsluta samtalet

- Avsluta telefonsamtalet

Slutligen så ska du parkera bilen. Slå på 360-kameran i CSDn.

- Slå på 360-kameran i CSDn (svep och tryck)

Därefter, blinka höger för att genomföra parkeringen.

- Slå på höger blinkers

Nu är VR testet klart så du kan ta av dig headsetet.

GENOMFÖR VR ENKÄTER

VR INTERVJU

INTRO

Vad är dina första tankar kring det du just upplevde?

Tänkte du på något som var speciellt bra eller dåligt?

Vad kände du när du tog av VR-headsetet?

PRESENCE OCH IMMERSION

Kändes det som att du var där, i själva bilen, körandes i miljön? (kroppsligt/fysiskt)

Kände du dig engagerad/fokuserad under testet?

MILJÖ OCH KONTEXT

Tänkte du på hur bilen rörde sig? Kändes det realistiskt? Påverkade det helhetsupplevelsen?

Vad är dina tankar kring hur realistiskt det såg ut (visuellt)? Påverkade det hur du utförde de olika uppgifterna?

Påverkade miljön utanför bilen hur du interagerade med system inne i bilen?

INTERAKTION MED BILENS SYSTEM

Under testet interagerade du med bilen med hjälp av dina händer. För vilka av uppgifterna tycker du att interaktionen fungerade bra/dåligt? Varför?

Kände du att du hade möjlighet att genomföra alla uppgifter på rätt sätt?

Var det något som var svårt när du utförde uppgifterna?

Hur reagerade skärmarna på din input?

HAPTIK

Hur upplevde du dina händer med avseende på hur synkroniserade de var med dina verkliga händer?

Upplevde du precisionen som tillräcklig?

Upplevde du att de fysiska representationerna av det virtuella innehållet var tillräckliga?

RÖST

Hur kändes det att kommunicera med testledarna?

Hur kändes det när vi pratade med dig? Påverkade det din känsla av att vara i bilen?

KÖRA VOLVO S90

Nu kommer du att få köra till PVE-receptionen/VAK-receptionen där nästa del av studien kommer att utföras. Vi kommer att be dig utföra ett par uppgifter, liknande de som du utförde i VR/Simulatorn.

Se till att du sitter bekvämt och att allt känns bra inställt

- Spänn fast säkerhetsbältet och ställ in sätet

Din första uppgift är att ange en destination via touch. Sätt destinationen till PVE/VAK-receptionen.

- Ange destination
    - PVE: Gunnar Engellaus väg 21, Gothenburg
    - VAK: Gunnar Engellaus väg 8, Gothenburg

Då är vi redo att åka. Blinka och kör ut.

- Blinka och börja kör mot receptionen

Nu ska du ringa ett telefonsamtal till Tor / Magnus.

- Ring ett telefonsamtal via touch (CSD)

Ingen svarar så du kan avsluta samtalet

- Avsluta telefonsamtalet

Slutligen så ska du parkera bilen. Slå på 360-kameran I CSDn.

- Slå på 360-kameran i CSDn (svep och tryck)

Parkera på anvisad plats

BIL INTERVJU

Nu när du har testat att köra en riktig bil, har det dykt upp några nya tankar kring det tidigare testet?

GENOMFÖR BIL ENKÄT

SIMULATOR TEST

Du kommer nu att få uppleva förarplatsen i en Körsimulator. Testledaren kommer sitta i passagerarsätet och ge instruktioner därifrån. Innan vi påbörjar körningen får du gärna bekanta dig med bilen i någon minut.

- Vänta i någon minut

Nu kommer vi be dig om att utföra ett antal uppgifter. Om någonting är otydligt så är det bara att fråga oss när som helst.

Se till att du sitter bekvämt

Nu kan du starta bilen

- Håll ned bromsen och tryck på startknappen

Din första uppgift är att ange en destination via touch. Sätt destinationen till Uppsala.

- Ange destination via touch (gör flera tryck på skärmen)

Välj ECO-rutten.

Gå tillbaka till huvudmenyn (görs av testledaren)

Nu är vi redo att åka. Blinka vänster, sväng ut, och kör längs gatan.

- Slå på vänster blinkers

Nu ska du ringa ett telefonsamtal. För att lämna kartan, tryck i hörnet nere till höger. Leta upp kontakten Christopher Rhem.

- Hitta kontakten via touch (CSD)

Om du hade velat ringa hade du klickat på knappen, men han är upptagen idag så vi vill helst inte störa honom.

- Gå tillbaka till huvudmenyn (görs av testledaren)

Slutligen så ska du parkera bilen vid sidan av vägen. Blinka och stanna bilen.

- Slå på blinkers och stanna

Innan du stänger av bilen vill vi att du kollar en väderprognos för de närmaste dagarna.

- Kolla väderprognosen

Nu är testet i körsimulatorn klart så du kan kliva ut ur bilen.

GENOMFÖR SIMULATOR ENKÄTER

SIMULATOR INTERVJU

INTRO

Vad är dina första tankar kring upplevelsen?

Tänkte du på något som var speciellt bra eller dåligt?

PRESENCE OCH IMMERSION

Kändes det som att du var där, I själva bilen, körandes i miljön? (kroppsligt/fysiskt)

Kände du dig engagerad/fokuserad under upplevelsen?

MILJÖ OCH KONTEXT

Tänkte du på hur bilen rörde sig? Kändes det realistiskt? Påverkade det helhetsupplevelsen?

Påverkade miljön utanför bilen din upplevelse av systemet inne i bilen?

INTERAKTION MED BILENS SYSTEM

Under testet interagerade du med bilen med hjälp av dina händer. För vilka av uppgifterna tycker du att interaktionen fungerade bra/dåligt? Varför?

Kände du att du hade möjlighet att genomföra alla uppgifter på rätt sätt?

Var det något som var svårt när du utförde uppgifterna?

Hur reagerade skärmarna på din input?

HAPTIK

Upplevde du att de fysiska representationerna av bilen var tillräckliga?

RÖST
Hur kändes det att kommunicera med testledarna?

Hur kändes det när vi pratade med dig? Påverkade det din känsla av att vara i bilen?

SAMMANFATTNING

GENOMFÖR SAMMANFATTANDE ENKÄT

SAMMANFATTANDE INTERVJU

Du har nu testat både simulatorn och VR utrustningen. Upplevde du några markanta skillnader? Om ja, kan du beskriva dem?

Fanns det några markanta skillnader med avseende på interaktionen?

Skulle du föredra något av testverktygen om du skulle delta i en liknande studie i framtiden? Varför/Varför inte?

Är det något du vill lägga till? Något som du tyckte var viktigt men som vi inte har berört?

APPENDIX 2: TEMPLATE OF USER EXPERIENCE QUESTIONNAIRE (UEQ)

Vänligen bedöm bilens system genom att kryssa en cirkel per rad.

	1	2	3	4	5	6	7	
Irriterande	O	O	O	O	O	O	O	Njutbar
Obegriplig	O	O	O	O	O	O	O	Begriplig
Kreativ	O	O	O	O	O	O	O	Tråkig
Lätt att lära sig	O	O	O	O	O	O	O	Svårt att lära sig
Värdefull	O	O	O	O	O	O	O	Värdelös
Tråkig	O	O	O	O	O	O	O	Spännande
Ointressant	O	O	O	O	O	O	O	Intressant
Oförutsägbar	O	O	O	O	O	O	O	Förutsägbar
Snabb	O	O	O	O	O	O	O	Långsam
Uppfinningsrik	O	O	O	O	O	O	O	Fantasilös
Hindrande	O	O	O	O	O	O	O	Stödjande
Bra	O	O	O	O	O	O	O	Dåligt
Komplicerad	O	O	O	O	O	O	O	Enkel
Möter inte behov	O	O	O	O	O	O	O	Möter behov
Bakåtsträvande	O	O	O	O	O	O	O	I framkant
Inte tilltalande	O	O	O	O	O	O	O	Tilltalande
Säker	O	O	O	O	O	O	O	Inte säker
Motiverande	O	O	O	O	O	O	O	Omotiverande
Möter förväntningar	O	O	O	O	O	O	O	Möter inte förväntningar
Ineffektiv	O	O	O	O	O	O	O	Effektiv
Tydlig	O	O	O	O	O	O	O	Förvirrande
Opraktisk	O	O	O	O	O	O	O	Praktisk
Strukturerad	O	O	O	O	O	O	O	Rörig
Estetisk	O	O	O	O	O	O	O	Oestetisk
Användbar	O	O	O	O	O	O	O	Inte användbar
Konservativ	O	O	O	O	O	O	O	Innovativ

Hur säker kände du dig på dina svar?

	1	2	3	4	5	6	7	
Mycket osäker	O	O	O	O	O	O	O	Mycket säker

APPENDIX 3: TEMPLATE OF SUMMARIZING QUESTIONNAIRE

	VR	Simulator
Vilket av testverktygen gav en upplevelse som var mest likt en riktig bil?	O	O
Under vilket av testen kände du dig mest uppslukad?	O	O
I vilket av testen föredrog du att interagera med bilen?	O	O

APPENDIX 4: MANUSCRIPT OF IN-DEPTH INTERVIEWS

PARTICIPANTS

1 technician

2 test leaders

1 project leader

1 concept leader

PURPOSE OF THE STUDY

(A) Identify stakeholders

- Who are they?
- What are their roles and tasks?

(B) Identify user needs among possible main users / operators / technicians etc.

- What type of tests does VCC want to conduct using the VR-rig
- What are the biggest drawbacks with today's solution

(C) Understand what has been done already, why certain decisions have been made and what the future plans are

FRÅGOR TILL TEKNIKERN

Roll / Bakgrund

Vad är din roll inom användartester och VR-området?

Vilka områden är du ansvarig för och hur mycket frihet har du att ta egna beslut? Var ifrån kommer beslutet att det ska göras ett VR-projekt? Är det någon annan som på förhand har bestämt vad som ska göras?

VR Generellt

Vad ser du för fördelar med VR för avdelningen?

Hur ser du framför dig att ni använder VR i framtiden? Om 5 år?

Riggen

I vilka sammanhang har du / kommer du ha kontakt med riggen?

Vad har du för mål med VR-riggen?

Vet du något om VR-riggens framtid? Ombyggnad etc?

Vilka är de största argumenten för att utveckla riggen?

Vad är planen vad gäller de fysiska delarna, t ex ratt, stol, instrumentbräda, växelspak, CSD, touchskärmar, rattknappar etc?

Hur ser du framför dig att skärmarna ska styras under tester? Kalibrerad skärm med sensorer eller wizard-of-oz?

Hur mycket utrymme krävs för alla nödvändiga interna komponenter? (T.ex. Dator, sensorer etc.)

Uppgifter

Vad tror du att du kommer ha för uppgifter kopplade till riggen, bortsett från att utveckla den? (Reparera / Säkerställa att mjukvara fungerar etc.?)

Vad är viktigt vid utformning av VR riggen för att underlätta ditt jobb?

Vad är det för typ av regelbundet underhåll som kommer behöva ske?

QUESTIONS FOR TEST LEADER 1

Role / Background

What is your role when it comes to user tests and VR?

What type of user tests are you performing? Which types are the most common? What is tested? How are the tests conducted? How often do they take place?

Which type of data are you collecting during a normal test? Is it collected through cameras, sensors etc.?

How much communication is made with test participants during a normal test?

How many persons use to be involved in normal tests? Who are you collaborating with during tests? Would you prefer to collaborate with more or fewer persons during these tests?

VR Generellt

What advantages do you think the department could get by using VR?

How do you imagine that the department will use VR in the future? In 5 years?

Riggen

In what ways do you "deal with" the VR-rig today? In what ways do you think you will?

What are your goals with the VR-rig?

What are the strongest argument for using the VR-rig?

How mobile do you think the rig has to be? How often will it be moved? In which way do you think it would be suitable to transport it?

Uppgifter

What do you think will be your tasks/responsibilities related to the VR-rig?

What is important to consider when designing the VR-rig to facilitate your work?

How do you think the interaction with the screens should work/ be controlled? Screens with integrated sensors so you can actually interact with the screens or wizard-of-oz, or maybe some other way?

Do you think that you need to have the possibility to discuss or interact with the interfaces together with the test participant during tests?

What kind of interactions are tested today and what kind of interactions do you think will be tested in the future?

FRÅGOR TILL TESTLEDARE 2

Roll / Bakgrund

Vad är din roll inom användartester och VR-området?

Vilka typer av användartest utför ni? Vilka är det vanligaste typerna? Vad testas? Hur görs testerna? Hur ofta utförs dem?

Hur mycket kommunikation sker mellan testledaren och testdeltagare under ett normalt test?

Hur många brukar vara involverade i dagens tester? Vilka är det i så fall du samarbetar med? Finns det önskemål om att kunna vara fler eller färre?

VR Generellt

Vad ser du för fördelar med VR för avdelningen?

Hur ser du framför dig att ni använder VR i framtiden? Om 5 år?

Riggen

Vad har du för mål med VR-riggen?

Vilka är de största argumenten för att använda VR-riggen?

Hur mobil behöver riggen vara? Hur ofta och vart kommer den flyttas? Hur tror det ni vore lämpligt att frakta den, ska den få plats i bakluckan?

Uppgifter

Vad tror du att du kommer ha för uppgifter kopplade till riggen?

Vad är viktigt vid utformning av VR riggen för att underlätta ditt jobb?

Vilken typ av data är det ni vill samla in? Bör riggen innehålla kameor, sensorer etc.?

Hur tycker du att interaktionen med skärmar borde fungera/kontrolleras? Skärm med sensorer, wizard-of-oz, något annat sätt?

Anser du att det finns ett behov av att sitta och diskutera/interagera med testperson under ett test?

Vilken typ av interaktioner är aktuella att testa idag och vilken typ av interaktioner tror du kommer att behöva testas i framtiden?

Finns det möjlighet att vara med och observera ett test eller titta på filmklipp från tidigare test för attförstå hur det vanligtvis går till på VCC?

FRÅGOR TILL PROJEKTLEDAREN

Roll / Bakgrund

Vad är din roll inom användartester och VR-området?

Är du insatt i VR-projekt som handlar om användartester?

Vilka områden är du ansvarig för och hur mycket frihet har du att ta egna beslut? Var ifrån kommer beslutet att det ska göras ett VR-projekt?

På vilket sätt har du en koppling till CTS VR?

När började VCC utforska HMD VR-teknik

VR Generellt

Vad ser du för fördelar med VR för VCC?

Hur ser du framför dig att ni använder VR i framtiden? Om 5 år? Vid fokus på gränssnitt i kupén, vad är dina takar då?

I de VR-projekten du är involverad i, vad har ni identifierat som viktigt där?

Vad ser du för trender inom VR?

Riggen

Hur ser du framför dig att VR-riggen skulle kunna användas och se ut? Har du någon vision?

Vet du något om VR-riggens framtid? Ombyggnad etc?

Vilka är de största argumenten enligt dig för att utveckla VR utrustningen?

Vilken typ av teknisk utrustning skulle vara lämplig samt realistisk att integrera? Touchskärmar, handksar, rattknappar etc

Hur ser du framför dig att skärmarna skulle kunna styras under tester? Kalibrerad skärm med sensorer eller wizard-of-oz?

Hur mycket utrymme krävs för alla nödvändiga interna komponenter? (T.ex. Dator, sensorer etc.)

Uppgifter

Kommer du ha någon koppling till riggen framöver, t.ex. om den flyttas?

Vad är det för typ av regelbundet underhåll som kommer behöva ske?

QUESTIONS FOR THE CONCEPT LEADER

Role / Background

What is your role when it comes to user tests and VR?

What type of user tests are you performing? Which types are the most common? What is tested? How are the tests conducted? How often do they take place?

How much communication is made with test participants during a normal test?

How many persons use to be involved in normal tests? Who are you collaborating with during tests? Would you prefer to collaborate with more or fewer persons during these tests?

When did you get involved in the VR?

When did VCC start exploring HMD VR technology?

VR in general

What advantages do you think the department could get by using VR?

How do you imagine that the department will use VR in the future? In 5 years?

The rig

What are your goals with the VR-rig?

What are the strongest argument for using the VR-rig?

How mobile do you think the rig has to be? How often will it be moved? In which way do you think it would be suitable to transport it?

What do you know about the future of the rig? Redesign etc.?

What is the plan for the physical parts of the rig, such as the seat, steering wheel, dashboard etc.?

What kind of technical equipment will be implemented in the rig? Touch screens, buttons on the steering wheel etc.?

How do you think screens should be controlled during user tests? Should they be based on a sensative screen or a wizard-of-oz principle for example?

How much space is required for all necessary internal components? (Such as computer, sensors etc.)

Tasks

What do you think will be your tasks/responsibilities related to the VR-rig?

What is important to consider when designing the VR-rig to facilitate your work?

Which type of data are you collecting during a normal test? Is it collected through cameras, sensors etc.?

How do you think the interaction with the screens should work/ be controlled? Screens with integrated sensors so you can actually interact with the screens or wizard-of-oz, or maybe some other way?

Do you think that you need to have the possibility to discuss or interact with the interfaces together with the test participant during tests?

What kind of interactions are tested today and what kind of interactions do you think will be tested in the future?

What kind of maintenance do you think will be required?

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