Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

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Heuristic Evaluation and Usability Heuristics in Virtual Reality

Master's thesis in Master in Interaction Design
Supervisor: Mariusz Nowostawski
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Sammendrag

Med stadige forbedringer i teknologi og maskinvare har Virtual Reality (VR) oppnådd en fornyet interesse og stadig flere VR-applikasjoner blir designet og utviklet for ulike bransjer og formål. Bransjer som har sett den potensielle verdien av VR er blant andre underholdningsindustrien, og mer spesifikt spillindustrien som tilbyr et økende antall spill for VR. Helsesektoren har også funnet teknologien nyttig til blant annet smertebehandling og behandling av fobier. Arkitekt-, ingeniør- og anleggsbransjen har tatt i bruk VR til ulike formål, som for eksempel til å bedre samarbeid, designgjennomganger, samt for å kunne involvere sluttbrukeren i større grad.

Denne fornyede interessen og det økende antallet VR-applikasjoner, har også ført til en økt innsats for å forbedre brukervennligheten. Mye av dette arbeidet omhandler forbedringer av teknologiske aspekter, og det er flere indikasjoner på at det fortsatt er betydelige bruksproblemer med flere VR-brukergrensesnitt. Denne studien søker å utforske hva årsaken til dette kan være, om det er forårsaket av mediet og dets utfordringer, eller om det kan være ha sammenheng med designprosessen.

Gjennom denne studien søker forskeren å utforske designprosessen til utøverne som jobber med design og utvikling av VR-applikasjoner. Videre søker den å undersøke om metoder fra 2D-HCI kan benyttes i designprosessen.

Resultatene fra studien tyder på at metoder og prosesser fra 2D-HCI, som heuristisk evaluering og heuristikk, kan benyttes til design og utvikling av VR-applikasjoner, dog med noe tilpasning. Videre viste studien viste at de fleste utøverne ikke er kjent med heuristikk og heuristisk evaluering. Studien finner også at de fleste industriutøverne bruker det som kan ses på som en prosess tilsvarende en brukersentrert designprosess, inkludert et tidlig fokus på brukere, en iterativ prosess og bruk av empiriske målinger (Gould and Lewis, 1985).

Abstract

Virtual Reality (VR) have recently received a renewed interest with improvements in technology and hardware, and there is an increasing number of VR-applications being designed and developed for various purposes. Industries utilizing this new opportunities are among others the entertainment industry, and more notably the gaming industry, offering an increasing number of VR games. The health sector have also found the technology useful in several areas such as pain management and treatment of phobias. The Architecture, Engineering and Construction (AEC) industry have utilized VR for various purposes such as improving collaboration, design reviews as well as increasing end-user involvement.

This renewed interest and increasing number of VR-applications have also lead to efforts towards improving the usability of VR. However, much of these efforts are concerned with technological aspects, and there are some indications that there are still significant issues concerning the usability of many Virtual Reality User Interfaces (VRUIs). This study seeks to explore why this might be, if it is caused by the medium and its challenges or if it might be caused by the methods used in the design process.

Through this study, the researcher seeks to explore the design process of industry practitioners working with design and development of VR-applications. Further it seeks to investigate whether methods from 2D-HCI can be successfully utilized in their process.

The findings from the study suggest that 2D-HCI methods and processes, such as heuristic evaluation and heuristics, can be adapted for design and development of VR-applications, although with some customization. The study found that most practitioners were not familiar with heuristics and heuristic evaluation. Further the study finds that most industry practitioners utilize what can be seen as a process similar to a UCD-process which commonly includes an early focus on users and tasks, and iterative process and empirical measurement (Gould and Lewis, 1985).

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This thesis marks the end of three years of studies in Interaction Design at NTNU Gjøvik. These years have been challenging and inspiring, and have provided me with skills and knowledge I am now exited to put to good use.

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Katrine Øvstegård
Smøla, 31st of May, 2019

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Abbreviations

AEC Architecture, Engineering and Construction
AR Augmented Reality
BIM Building Information Model/Modeling
DIVE Dynamic Interactive Virtual Environment
GUI Graphical User Interface
HCI Human Computer Interaction
HMD Head Mounted Device
MR Mixed Reality
UCD User-Centred Design
UI User Interface
UX User Experience
VR Virtual Reality
VRUI Virtual Reality User Interface

1 Introduction

1.1 Background and motivation

The initial inspiration leading the researcher into this topic was a series of experiences with VR technology and applications through previous work and studies, and more recently through studies and reflections on the possibilities and challenges with VR in the course *Mobile Media and Technology* at the University of Sydney. These experiences and reflections made the researcher optimistic towards possibilities within the technology and medium, but also had the researcher wondering why usability is seemingly such a significant issue in Virtual Reality User Interfaces (VRUIs).

Was the issues caused by the technology and medium itself, was it just more complex than other interfaces and thus more challenging to work with? Or did it have something to do with the methods utilized in the process, were they not suitable for the purpose?

1.2 Problem Description

As the VR-industry is growing and an increasing number of industries and businesses find ways to utilize VR in order to solve various issues, tasks and to improve their businesses, VR is reaching a greater audience – many of whom never interacted with this new medium before. In contrast to the shift from desktops and laptops to mobile, one might claim VR is a very different medium, without the flat displays we have been used to.

The VR industry is claimed to be highly technology driven (Jerald, 2016, Bowman *et al.*, 2017) having a great focus on solving technical issues and exploring the possibilities within the technology. Jerald suggest that continuous technological advances might solve many of the technology-related usability issues, but not all, further suggesting that usability will probably continue to be a challenge for the practitioners involved in the future (Jerald, 2016). Bowman et.al. claims that most 3D UIs (User Interfaces) still are *"either straightforward or lack usability"* (Bowman *et al.*, 2017), and Jerald further suggest that parts of VR's challenges in becoming a commercial hit, can be traced back to poorly designed interfaces (Jerald, 2016).

As the industry and technology is maturing, design and usability is gaining more interest among both researchers and practitioners. Even though efforts are made to both improve the usability of VR-applications and the methods available for the practitioners working with them, limited research have been done on how practitioners utilize this newly gained academic knowledge and if they do utilize it at all.

This research project aims to somehow decrease this gap between the academic world and practice, and to direct more focus towards the improvements of usability in VRUIs. By talking to practitioners about their design process, the researcher's ambition is to learn more about what methods they utilize as well as how they address issues of usability.

Additionally, one objective is to explore how well methods based in 2D-HCI work when implemented in the design process of VRUIs. As this would have been a too broad scope for the limitations of the study, this was further investigated through discussing the role of heuristic evaluation and usability heuristics.

1.3 Research Questions

The following research questions and hypothesis have guided research process:

Research question 1 (RQ1):
Have practitioners in the virtual reality industry implemented VR-specific usability heuristics in their design process?

a) Have they utilized other usability heuristics and principles?
b) What design methods are practitioners utilizing in the design process of VRUIs*?*

Hypothesis 1 (H1, connected to RQ1):
Most industry practitioners are unfamiliar with heuristic evaluation as a method as well as heuristics.

Research question 2 (RQ2):
What usability heuristics for VRUIs are available in the academic literature?

a) How are these heuristics developed?
b) How are they utilized and evaluated?

Research question 3 (RQ3):
What are practitioners attitudes towards the heuristic evaluation method and heuristics when they are made familiar with it?

a) What benefits and challenges do practitioners find with the method?
b) How do the practitioners evaluate and view the heuristics?

1.4 Research contributions

Through interviews with industry practitioners about their design process and a literature review presenting an overview of available usability heuristics for VRUIs, the relationship between the academic knowledge and the real life experience of the industry practitioners will be investigated. This might provide insight into the design process and methods utilized by the VR-industry, as well as an indication towards if the industry utilize the academic research available in the field. More specifically the interviews will provide an indication towards if industry practitioners utilize heuristic evaluation and heuristics in their process.

The results from the literature review will provide an overview of available usability heuristics for VRUIs and will give an indication towards whether further work is needed in this research area.

The implementation of a heuristic evaluation together with industry practitioners, will provide insight towards the efficiency of the method and utilized heuristics, although limited. More importantly, and according to the objectives of the study, it will give insight

into the attitudes of the practitioners, towards the method and the available heuristics. Further it will indicate if they find the method and the heuristics presented to them useful and applicable to their own design process.

1.5 Project scope and limitations

The scope of this study is limited to immersive VR which is utilized with HMDs, what most people commonly refer to when speaking of VR, and additionally the type of VR the industry practitioners in this study work with. Further, the main limitations of this study are a small selection for both interviews and the heuristic evaluation, which might implicate how valid the results from these activities are.

1.6 Thesis structure

Chapter 1, Introduction, described the researchers background and motivation for studying this topic. Further the problem description was presented along with the research questions guiding the study. Additionally the planned contributions and the scope and limitations of the study was described.

Chapter 2, Background, provide the reader with background material related to the study, describing and discussing matter relevant for the topic such as UCD and a UCD-process, evaluation methods for UIs and studies on the improvements of usability in VR.

Chapter 3, Methodology, describes the methodology chosen for the research project. It begins with a description of how the interviews with industry practitioners were planned, implemented and analyzed and continuous with explaining how the literature review was conducted. Finally the approach of the heuristic evaluation, and the interviews prior to and following the evaluation are described.

Chapter 4, Results, describes the insights and knowledge gained from the interviews with industry practitioners, it presents the results from the literature review and further it describes the attitudes of practitioners when made familiar with heuristic evaluation and heuristics.

Chapter 5, Discussion, first presents a reflection of the research process as well as the utilized methods. Following is a discussion of the findings from the study before a summary and some concluding comments. Finally the contributions of the study is described as well as an indication towards possible topics for further study.

2 Background and related literature

2.1 Virtual Reality

Virtual Reality (VR) is of often seen and discussed as a new and emerging technology although Ivan Sutherland (Sutherland, 1968) presented a HMD over 40 years ago. Recent advances in miniaturisation and more consumer friendly hardware, made available by large companies behind HMDs such as HTC Vive (www.vive.com), Occulus (www.occulus.com) and Magic Leap (www.magicleap.com), as well as better and more available content, have facilitated a renewed interest for VR as a technology and medium.

2.1.1 Implementation of Virtual Reality applications

VR's aims towards gaining consumer success have been debated and some have predicted that the technology and medium is more likely to stay a niche and be commercially overrunned by MR and AR (Lomas, 2017). Where Lomas pin much of the failure of commercial success to clunky hardware and low-quality content, others have pointed towards lacking usability in the UIs of many VR-applications as part of the reason (Bowman *et al.*, 2017, Jerald, 2016).

Despite the debate on VR becoming a commercial success or not, and claimed issues with UI usability, several industries have started to see possibilities within the technology and medium. VR have already been utilized to solve various issues and tasks across different industries, and immersive technology have received an increasing research interest in recent years (Suh and Prophet, 2018). Below, some examples of industries taking part in the development of VR-applications are mentioned briefly.

The games industry early embraced VR and is one of the significant contributors to the VR industry. This might not be surprising, as the gaming industry have been creating complex 3D worlds and environments for a long time in video games for traditional displays such as consoles, PCs and mobile phones. Several new games are continuously being developed and published such as BeatSaber (www.beatsaber.com) aimed at a more mainstream audience, as well as already established games being made available for VR. Alongside an increasing level of games being develop for VR, there is also increased research efforts in areas such as presence and user experience, (Carter and Potter, 2016) and usability and guidelines for VR games (Desurvire and Kreminski, 2018).

In the health industry VR have been utilized to develop applications for pain management and treatment of mental conditions such as anxiety and phobias. One example of such an applications is the immersive VR game SnowWorld (www.hitl.washington.edu/projects/vrpain) aimed towards helping patients undergoing painful treatments of burn damages manage and relieve their pain. Additionally VR have been used to increase the wellbeing among elderly in services such as Rendever

(www.rendever.com), allowing elderly to among other things relive geographical places of interest, or experience sites they were never able to visit in the past.

The Architecture, Engineering and Construction (AEC) industry traditionally have extensive experience with visualizing and working with 3D environments. The AEC industry widely make use of BIMs (Building Information Modeling/Models) in their projects (Heydarian *et al.*, 2015). Research efforts have been directed towards developing and evaluating applications for various purposes such as for design reviews, collaboration and improved decision making in AEC-projects (Du *et al.*, 2018, Paes and Irizarry, 2018).

2.2 User Interfaces

This study specifically looks into the design and evaluation of Virtual Reality User Interfaces (VRUIs). A User Interface (UI) can be described as the medium where the communication between the user and the system or computer take place (Bowman *et al.*, 2017). Simply put the user gives input to the computer through an input device, and receives output through and output device. These input and output devices, also referred to as components, facilitate the communication between the user and the system.

In a traditional UI for a desktop computer the input components might include; a keyboard, a computer mouse and sometimes audio input. The output components of such as system usually includes; a display – in this setting usually a desktop/laptop monitor – and audio (speakers). On a smartphone the output components usually include the smartphone screen (the display), audio and sometimes also haptic feedback. The input components usually includes; touch and gestures, and audio recordings.

The UI described above are commonly referred to as *Graphical User Interfaces* (GUI) and to a great extent these interface make us of the WIMP-paradigm, consisting of Windows, Icons, Menus and Pointer. Most of the interfaces we see around us today are some form of a GUI incorporating this paradigm, including smartphones. Even though smartphones have brought with it UIs incorporating novel interaction techniques in the form of gestures, touch and haptics, they still utilize much of the GUI elements and conventions we are familiar with (Preece, Rogers and Sharp, 2015).

VRUIs can be described to be somewhat more complex, including more components than that of a common GUI. The input components of a VRUI as described in this study commonly consist of a hand controllers, tracking devices tracking eye, head and body movement, and sometimes also audio input. The output components commonly consist of a display (HMD), audio (speakers) and haptics (Bowman *et al.*, 2017).

Traditionally, VR have been described to consist of four interaction types: *selection*, *manipulation*, *navigation* and *system* (Blom and Beckhaus, 2014). As *navigation* commonly can refer to both navigating a virtual space as well as navigating menus in 2D UIs, another way of defining ways of interaction in VR might be useful. Bowman *et al.* (2017) sort VR interaction techniques into the following categories: *selection* and *manipulation*, *travel* and *system control*.

Selection and manipulation describes how a user can select objects in an environment and how this object can be manipulated. One example can be if a user wants to pick up a ball from the ground of a virtual environment and throw it, which would include both selection and manipulation techniques. Travel describes ways a user can navigate the virtual environments and includes among other metaphors for walking and elements of wayfinding.

System control describes ways the user can control the system, commonly through various menus or commands (Bowman et al., 2017).

2.3 User-Centered Design and usability

User-Centered Design (UCD) can be seen more as a philosophy than a technique, and it is commonly emphasized that a user-centered approach is important in several design disciplines, including interaction design. UCD have a high focus on users and tasks, and continuous to involve the users of a system, product or service throughout the design process (Baxter and Courage, 2005). UCD can be characterized by three principles, for designing for usability (Gould and Lewis, 1985); early focus on users and tasks, empirical measurement and a iterative design.

Usability, as described by (Merriam-Webster, 2018b), is *"something being usable"*; that something *"something is capable of being used or convenient or practical to use"* (Merriam-Webster, 2018a). The Nielsen Norman Group (www.nngroup.com) define usability by five quality components; *learnability, efficiency, memorability, errors* and *satisfaction* (Nielsen, 2012).

2.3.1 User-Centered Design-process

The stages or steps in a UCD-process are described somewhat differently depending on who is describing them. Some might describe it as a four phase process consisting of: *Concept, Design, Development* and *Release* (Baxter and Courage, 2005). IDEO.org describes it as a three phase process incorporating: *Inspiration, Ideation* and *Implementation* (IDEO.org, *2015).* A third describes the process as four activities: *Understanding*, *Envisionment*, *Evaluation* and *Design (Benyon, 2014)*.

The stages, phases or activities might be defined differently by different authors, but they all aim to incorporate the principles of UCD throughout the whole process. The authors mentioned above (Baxter and Courage, 2005, Benyon, 2014, IDEO.org, 2015) all described the process as iterative process, where one might jump back and forth between phases and activities. Benyon (2014) elaborates this further by explaining how one might begin working on an interactive system at any point of the process and that the activities don't necessarily follow a specific order.

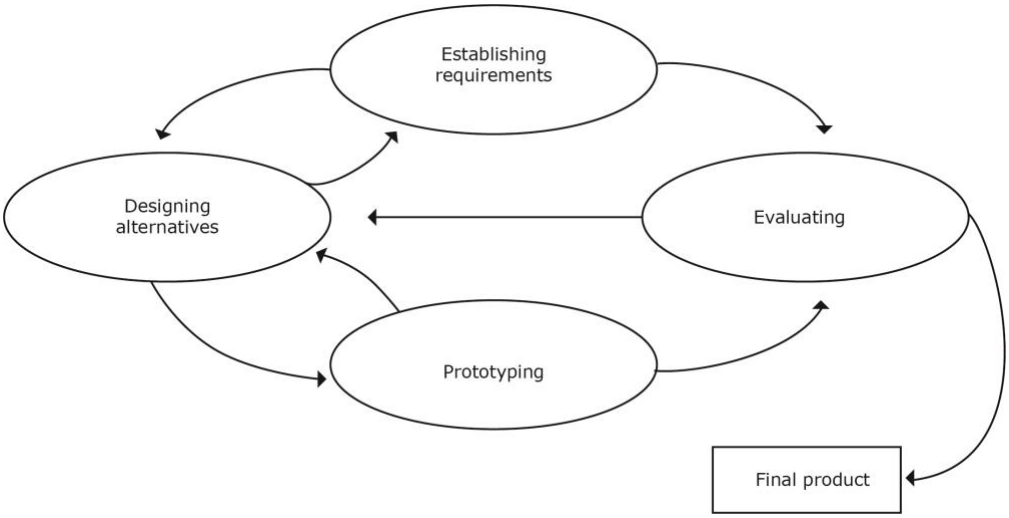


Figure 2.1: Interaction design lifecycle model (Preece, Rogers and Sharp, 2015)

A UCD-process can utilize and implement a range of different methods and activities in an approach towards designing a highly functional and usable digital product or service. The activities and methods mentioned next are structured according to the cycle in *Figure 2.1* (Preece, Rogers and Sharp, 2015). However, as some authors have pointed out methods might be utilized across different steps in the process (Benyon, 2014).

Establishing requirements might include, but are not limited to, activities such as interviews with users, observations, PACT-analysis, development of personas and scenarios, task analysis and development of usability goals among others. In a design phase producing alternative designs, various ideation techniques such as brainstorming and ways of sketching and developing concepts might be implemented. In a prototyping phase prototypes of different levels of fidelity might be developed, from low-fidelity paper prototypes to high-fidelity, highly functioning prototypes. Surveys, user tests, heuristic evaluations and cognitive walkthrough among others, are methods that can be implemented for evaluating a digital product or service (Baxter and Courage, 2005, Benyon, 2014, Preece, Rogers and Sharp, 2015)

2.3.2 Efforts towards better usability in VR

While incorporating UCD aspects into a VR design and development process, one study found encouraging results for utilizing such a process, as they by the end of the project had empirical results proving the applications usability. The study utilized a combination of expert evaluations, followed up by formative and finally summative evaluations in an iterative process which they found particularly useful (Hix, Deborah *et al.*, 1999).

Other efforts towards increasing the usability of VR-applications include among others a questionnaire designed to measure the users attitudes and experience with an application in order to determine its usability (Kalawsky, 1999).

Further, various frameworks have been developed in order to aid the process of designing and developing for VR, such as a framework focusing on presence and flow aiming to provide a method of measuring the holistic human experience (Takatalo, Nyman and Laaksonen, 2008). A study defining the components of what they describe as "*Dynamic*

Interactive Virtual Environments" (DIVE) suggest that having a world to be both active as well as reactive, is what makes a VR experience interesting and engaging for its users (Blom and Beckhaus, 2014).

A sense of presence, the user having the impression of "being there", is commonly seen as a critical aspect of the human experience and further they usability of VR-applications. This have led to studies on what aspects might influence the sense of presence such as one study investigating how immersive an experience needs to be in order to for the user to experience a sense of presence (Cummings and Bailenson, 2016).

2.4 Ways of evaluating User Interfaces

Evaluation is accepted as an important part of any design process (Benyon, 2014, Preece, Rogers and Sharp, 2015, Shneiderman and Plaisant, 2010). There is a range of different methods practitioners can utilize to evaluate their designs. These evaluation methods can be described and classified in various ways.

Benyon (2014) describes two main categories of evaluation: *expert-based* methods including methods such as cognitive walkthroughs and heuristic evaluations and *participant-based* methods which entail user testing in various forms.

(Preece, Rogers and Sharp, 2015) describe evaluation methods as sorted by three major categories based to what extent the evaluator can control the circumstances of the evaluation and the level of user participation. Two of the categories both include user participation; evaluations in a controlled setting and evaluations in natural settings. The third category is any evaluation not including users.

2.4.1 Empirical evaluations and usability inspection methods

Empirical measurement, commonly referred to as user testing, is one of the key principles of a User-Centred Design-process (Baxter and Courage, 2005). As mentioned earlier, such processes emphasize an early involvement of users and a continuous involvement to ensure the products and services developed meet the users' needs.

Even though it is commonly acknowledged that user testing is one of the evaluation methods providing the richest data, and critical to designing and developing a product that will provide value for its users and answer to user needs (Baxter and Courage, 2005, Benyon, 2014, Preece, Rogers and Sharp, 2015), in various projects it might be implemented only in a limited manner, or not at all (Mack and Nielsen, 1994b).

The lack of implementation of empirical evaluations can be caused be several reasons such as a project having restricted resources in terms of finances or time, or that a project lacks access to its end-users.

To support projects and teams with limited resources and projects that for various reasons could not implement, or could only conduct limited user testing, Mack and Nielsen along with several other researcher within the field of usability engineering aimed to develop methods that could be used as alternatives and supplements to traditional user testing. Through a workshop at the *ACM CHI'92* conference, several methods were presented and tested. The methods were further developed, evaluated and presented in the book *Usability Inspection Methods* (Mack and Nielsen, 1994a), among the methods presented was heuristic evaluation .

2.5 Heuristic evaluation

2.5.1 Background and history

Rolf Molich and Jakob Nielsen (1990b) introduced heuristic evaluation as an informal way of evaluating the usability of User Interfaces (UIs). The authors express an ambition of improving and providing more research on a way of evaluating UIs that practitioners already utilized in their practical work.

They describe evaluating a UI *heuristically* as the process of the practitioner looking at the UI and judging its quality based on their own knowledge and experience. Further they suggest such evaluations should ideally be based upon recognized usability principles, noting that the guidelines available at the time consisted of a large number of guidelines, not necessarily suitable for such an evaluation.

The guiding principles or heuristics used in the first description of the heuristic evaluation method (Molich and Nielsen, 1990b) were based on previous work by the two authors (Molich and Nielsen, 1990a) suggesting that guiding principles for usability in HCI was needed in order to design better interfaces. A refined and extended version of these heuristics were later presented by Nielsen (1994b).

2.5.2 Conducting a heuristic evaluation

As described by Nielsen (1994b) heuristic in its simplest form consists of three basic steps:

1. Evaluators individually go through the interface first time to become familiar with the interface
2. Evaluators individually go through the interface second time where they focus on individual elements and check if they comply with basic usability principles (the heuristics)
3. The findings from the evaluators are combined

Nielsen also suggest that a debriefing session including all the evaluators can be helpful and add value to the results of from the heuristic evaluation in addition to making it easier for the design and developer team to use the results as a base for further work. Additionally, he recommends adding a severity rating to the issues in order to prioritize them easier.

ID	**Name**	**Description**
1	*Visibility of system status*	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2	*Match between system and the real world*	The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3	*User control and freedom*	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

4	*Consistency and standards*	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5	*Error prevention*	Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6	*Recognition rather than recall*	Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7	*Flexibility and efficiency of use*	Accelerators — unseen by the novice user — may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
8	*Aesthetic and minimalist design*	Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9	*Help users recognize, diagnose, and recover from errors*	Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10	*Help and documentation*	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Table 2.1: 10 Usability Heuristics for User Interfaces (Nielsen, 1994b)

2.5.3 Debate, criticism and utilization

The heuristics and the method as introduced by Molich and Nielsen (1990b) and later refined and described by Nielsen (1994b) are, although widely accepted and recognized also debated.

The heuristics themselves as presented by Nielsen (1994b) are frequently the topic of the debate. Several researchers have created and presented such heuristics both based on separate studies and work (Shneiderman and Plaisant, 2010, Johnson, 2013) and a mix between existing heuristics and guidelines (Benyon, 2014). Accordingly, several question how practitioners can choose and judge the quality among sets of heuristics, both general purpose and domain or technology specific (Hvannberg, Halldorsdottir and Rudinsky, 2012).

Comparing Nielsen’s heuristics to other general purpose heuristics are one approach towards studying the heuristics effectiveness. When comparing Nielsen’s heuristics with other general purpose heuristics, one study found that there were no significant difference between the heuristic sets (Hvannberg, Law and Lérusdóttir, 2006). Another study working

on improving the effectiveness of heuristic evaluation by altering the method points out that Nielsen's heuristics are not taking into consideration the aspect of *subjective satisfaction,* an acknowledged and important part of usability, and also part of Nielsen's own usability model, which the authors claim have limited connection to Nielsen's heuristic set (Alonso-Ríos, Mosqueira-Rey and Moret-Bonillo, 2018).

The heuristic evaluation technique as presented by Nielsen (1994a) have remained, in broad terms, more or less unchanged, and much of the research focus have been about evaluating its effectiveness compared with other methods for evaluating UIs (Anganes *et al.*, 2016) rather than improving and refining the technique itself.

Critique of the heuristic evaluation method includes its seemingly lack of consistency in reported issues across different evaluators, a high rate of *false positives* and mostly minor usability issues being reported by evaluators as well as some major usability issues not being detected by evaluators (Benyon, 2014). Some have, while acknowledged that the method have some weaknesses as it is not capable of discovering and assessing all usability issues, suggested that it still can be a useful tool for the purpose of assessing usability of UIs. More specifically they suggest the method can perform well when complemented by other methods (Gonzalez-Holland *et al.*, 2017).

Despite some critique and debate, heuristic evaluation is still a commonly used method among practitioners and appreciated for being flexible, quick, and cheap compared of several other usability evaluation methods. Heuristic evaluation was reported by usability practitioners in the US to be the technique most used in 2009 (Association, 2009)

The evaluation technique have been utilized by several practitioners and researchers in an effort towards evaluating and improving the usability of various digital products, also within the field of VR (Paes and Irizarry, 2018, Tromp *et al.*, 2018, Altarteer *et al.*, 2017, Hix, Deborah *et al.*, 1999).

2.5.4 Development and utilization of specific heuristics

As new technology, applications and domains emerge, researchers have seen a need for more specific heuristics, more suited to specific interfaces. Domain and technology specific heuristics have been developed for a variety of domains and technologies and commonly the studies find the specific heuristics more effective than general purpose heuristics (Mankoff *et al.*, 2003, Joyce and Lilley, 2014, Carter and Potter, 2016).

Although many studies find that specific heuristic are more effective than general purpose heuristics, some have raised concerns that many specific heuristics sets are developed and published rapidly, as a result of the need of such as set in the moment, and that many of them lack follow up studies and extensive research on their effectiveness (Anganes *et al.*, 2016). Additionally a lack of a structured methodology (or the description of one) have been cause of some critique (Quinones, Rusu and Rusu, 2018).

2.6 Summarizing comments

In 2D-HCI efforts have been directed towards overall improvements of usability in digital products as seen in studies and educational literature aiming to provide practitioners with supporting methods and tools such as evaluation methods, an understanding of human

factors, user interface components and an overall understanding of the importance of including users in the process, utilizing a iterative process and empirical measurements.

Similarly, efforts have been made in an attempt to improve the usability of VRUIs. However, the literature on this is somehow limited. Additionally, much of the literature is to a large extent concerned with types of VR such as CAVE and VR utilizing displays such as workbenches and large displays. Less literature is available for the emerging type of immersive HMD-VR we now see coming into the consumer market and receiving more attention by businesses and developers.

There might be an indication towards that a utilization of UCD and methods from traditional 2D-HCI can be successfully implemented in the context of VR design and development, particularly expert reviews combined with empirical measurements in an iterative process (Hix, D. *et al.*, 1999). However, some report that lacking HCI-knowledge among VR designers and developers might be challenging when implementing methods such as heuristic evaluation (Gault and Sutcliffe, 2004, Sutcliffe *et al.*, 2018).

In the following chapters the researcher will explore the current design process of VR designers and developers aiming to gain insight into how they work as well as finding an indication towards whether or not the practitioners are utilizing methods from the academic literature developed specifically for VR such as usability heuristics. Additionally an investigation towards what usability heuristics are available for VRUIs in the academic literature, as well as exploring a practical implementation of heuristic evaluation utilizing usability heuristics together with evaluators who work with design and development of VRUIs on a daily basis.

3 Methodology

The following chapter describes the research design and strategy, the methodology used to collect and analyse data, as well as interpreting this data (Leedy and Ormrod, 2014).

The study utilizes a mostly qualitative approach, as the objectives of the study are focused on exploring and gaining insights into the methods and processes utilized in designing Virtual Reality User Interfaces (VRUIs). Thus, the data obtained might be difficult to measure in a quantitative manner. However, some of the methodology chosen for this study have incorporated some measures, that might be associated with a quantitative approach (Bryman, 2016)

The study can be divided into two main phases (in addition to the third phase analysing the collected data), where the first phase guides the strategy for implementing the second:

- *Phase 1* consisted of interviews with industry practitioners and a literature review. The data collected from these two methods guided the evaluation in phase 2.
- *Phase 2* consisted of an evaluation of the heuristic evaluation method and two heuristic sets, together with industry practitioners.

3.1 Interviews with industry practitioners

The main objectives of the interviews was to explore and learn about what methods industry practitioners utilized in design and evaluation of VRUIs, and how these utilized methods related those described in the academic literature, either from the traditional 2D-HCI field or to more recent work in VR-HCI.

3.1.1 Collecting data

Recruitment and selection

The recruitment and selection process began when the study was started, continuing through the whole project until the remaining time would not allow for any more interviews to be done. The researcher had limited knowledge about the Norwegian VR-industry and of who was working with design of VRUIs. Thus, participants for the interviews were chosen based on the participants willingness to participate, and the researcher relied on the knowledge of the industry practitioners themselves in verifying whether or not they were suitable for the study. When approaching the participants, the researcher shared information about the topic for the study, as well as the objectives of the interviews. It was then mainly up to the participants to decide if they were suited for the interviews and if they had time and motivation to take part in the interview.

This approach is commonly referred to as convenience sampling (Preece, Rogers and Sharp, 2015) and the researcher used the following strategies to find participants:

- reaching out to friends, fellow students and acquaintances working in, or doing studies in fields such as design, IT and programming.
- potential participants were also found and contacted by doing Google (www.google.com) searches for companies working with design and development of VR-applications, additionally, some interview participants tipped the researcher about potential interesting interview participants, and these were also contacted.
- The researcher's collaboration partner also contributed with advice on potential relevant businesses and practitioners to contact, and this advice was followed up on.

Conducting the interviews

Interviews were conducted mainly through Skype or other video conferencing services with one exception which was conducted in person. Conducting the interviews in person would be ideal, however, limitations in terms of resources and geographic distances meant most of the interviews had to be done remotely. Prior to the interviews the participants answered a questionnaire regarding their experience with design and development of VRUIs, their educational background as well as familiarity with heuristic evaluation and heuristics (see Appendix 1). The questionnaire was distributed to most of the participants through the online survey service SurveyMonkey (www.surveymonkey.com). If not distributed via SurveyMonkey, the questions from the sruvey would be read out to the participants while the researcher would note their answers.

As the objective was to use the interviews to gain insight into the real world experience of the practitioners, a semi-structured interview approach was found to be suitable, as this type of interviews provides structure and guidance during the interview meanwhile allowing for the researcher to follow up on potential important and interesting themes based on the answers from the interviewees (Bryman, 2016, Baxter and Courage, 2005). An interview protocol with questions and talking points was developed to guide the interview process (see Appendix 2) Significant time was spent developing and writing the questions, aiming to make sure they were understandable for the participants and impartial so that the interviewees would answer freely and without being led by the researcher's bias (Baxter and Courage, 2005).

A pilot interview was conducted to ensure that the questions were suitable and understandable for potential participants. Such a pilot interview was also useful in training the researcher in regards to balancing active listening with contributing to the conversation in order to keep it flowing (Brinkmann and Kvale, 2015). This also gave the researcher a good indicator of the time frame for the interviews as well as the flow of the conversation.

All the interviews were recorded, apart from one where the recording was missing due to a technical error, and notes were taken by the researcher during the interviews. Effort was made to transcribe the recordings and supplement them with the researchers notes shortly after the interviews were finished. By transcribing within a short time after the interviews, the researcher aimed to prevent data from being lost as a result of failing memory of the researcher (Baxter and Courage, 2005). These transcriptions were used as the source of data for the later analysis.

The transcriptions recalled the interview word-by-word, although not verbatim. Words like "ehm", "mhm" and similar were left out, as were differences in intonation, laughter and short pauses. As the interviews were concerned with reporting on, rather than interpreting, the attitudes and meanings described by the practitioners this was found to be a suitable approach (Brinkmann and Kvale, 2015).

3.1.2 Data analysis

Data analysis started immediately after the recordings of the interviews were transcribed. As the researcher read through the transcripts noting themes and statements of interest. Later a software tool, NVivo 12, for coding qualitative data was utilized in order to support the coding process (www.qsrinternational.com/nvivo/home).

Coding of data is a common approach for analysis in qualitative studies, and was also utilized in this study. Although coding is acknowledged for being a reasonable and common way of structuring qualitative data, it is also debated (Brinkmann and Kvale, 2015). This study aimed to use the codes and themes more as guidance in interpreting the data, and guiding the narrative, more than an approach of quantifying the data, accordingly there was little emphasis on how many times the codes were used and the size of each theme.

The codes and the derived themes from the codes were developed in an iterative process. The coding process was data-driven, as the codes were created during the analysis while sorting data into the codes. rather than data being sorted into predefined codes (Bryman, 2016).

This process started already during transcription of the recording with the researcher noting and highlighting potential interesting data while transcribing. Following the transcriptions the researcher read through all the transcripts as soon as they were transcribed, assigning more codes while reading through the transcripts a second time. This lead to a large number of codes being developed, which were then sorted into broader themes or categories.

After the first iteration of the coding process, all codes were taken out of the broader themes and resorted into the themes once more while the researcher read through all instances of coded data, clearing out any duplicates and adding data missed in the first iterations. The third iteration consisted of a re-definition of the broader themes and sorting the codes accordingly. This thorough and iterative coding process made connections between themes and sub-categories, and between the statements more visible for the researcher.

The researcher use quotes from the interview transcripts in the results chapter of this thesis. The interviews were originally done in Norwegian, and thus the quotes are translated to English by the researcher for this thesis report.

3.2 Literature review

The objectives of the literature review was to uncover heuristics specifically developed for Virtual Reality User Interfaces (VRUIs). Further the review aimed to explore the methodology used to develop these heuristic, as well as gaining insight into how they were utilized and evaluated.

A systematic search approach

A systematic approach for the literature search was sought while aiming to uncover VR specific heuristic sets. The objectives of incorporating a more systematic approach is that such an approach is claimed to be a more transparent process, a quality that can be seen as increasing the validity of a study as it will make it easier for other researchers to recreate. It can be challenging to incorporate a fully systematic literature review in its purest sense in a thesis research project (Bryman, 2016).

This review incorporated a search strategy with predefined inclusion and exclusion criteria. Systematic reviews are commonly quite extensive, utilizing several search strings as well as databases. Such an extensive search strategy often yield a large set of literature and reviewing thus often can be time consuming. This study have a limited time resources and so the scope of this review was narrowed down to fit within the limitations of the study. Additionally, a systematic review often incorporate several reviewers whereas this study, being a master thesis research project, is conducted by one single researcher.

Search strategy

The systematic literature search strategy included two search strings that were used to search two databases: Scopus (www.scopus.com) and Web of Science (www.webofknowledge.com). The secondary search string was included in order to ensure a broader set of results, leaving out the search phrase "user interfaces" to open up for other ways of describing various systems. The exclusion and inclusion criteria as well as search limitations are shown in *Figure 3.1.*

After conducting this search and gathering the literature from its results, the researcher opened up for following leads from the found literature and thus taking a more narrative approach after the initial systematic literature search was done. Articles found using this way and further investigated in the review was stated in the review.

	Main search string	**Secondary search string**
	"Virtual Reality" AND "Heuristic Evaluation" OR Heuristic* AND "User Interface*" OR "User Interface Design"	"Virtual Reality" AND "Heuristic Evaluation" OR Heuristic*
Limitations	• Year published 1999–2019 • Only literature in English	• Year published 1999–2019 • Only literature in English
Inclusion criteria	• Literature about HMD-based Virtual Reality (VR) • Studies comparing different heuristic sets – either comparing two or more VR specific sets, or comparing VR specific sets to general purpose sets	• Literature about HMD-based Virtual Reality (VR) • Studies comparing different heuristic sets – either comparing two or more VR specific sets, or comparing VR specific sets to general purpose sets
Exclusion criteria	• Articles about Augmented Reality (AR)	• Articles about Augmented Reality (AR)

	• Articles using the heuristics as a means of evaluating a user interface or system – not evaluating or discussing the heuristics themselves or the argument for choosing them • Comparison studies using heuristics sets where none of the sets are developed specifically for VR • Literature without authors	• Articles using the heuristics as a means of evaluating a user interface or system – not evaluating or discussing the heuristics themselves or the argument for choosing them • Comparison studies using heuristics sets where none of the sets are developed specifically for VR • Literature without authors

Table 3.1: Literature review search strategy

3.3 Evaluation with industry practitioners

The evaluation consisted of, in addition to the heuristic evaluation of a VRUI done by two individual practitioners working on the same VRUI in the same organization, the following activities: an explorative and unstructured interview with one of the practitioners prior to the evaluation, a structured interview with each of the two participants directly after the heuristic evaluation, as well as an unstructured group interview at the end of the evaluation including both practitioners.

The main objective of conducting a heuristic evaluation together with industry practitioners was to explore the performance of the method and the chosen heuristics in a practical and realistic context. Few of the practitioners in the previous interview were familiar with heuristic evaluation and heuristics. This implementation of heuristic evaluation on a VRUI by VR industry practitioners, accordingly sought to explore whether this was because the method might not be suitable for this purpose, or if it was more likely to be coincidental.

The unstructured interview prior to the evaluation aimed to explore the process of the practitioners participating in the evaluation and to compare their process to the ones described by practitioners from the previous interviews (see section 3.2).

The structured interview with the individual evaluators directly after the heuristic evaluation and the following unstructured group interview aimed to explore the evaluators attitudes towards the method as well as the heuristics used in the evaluation. In the group interview both evaluators were presented with the heuristic set which the other evaluator used in their evaluation, enabling a discussion about the two different sets.

Participants and selection

The participants were selected by convenience sampling (Preece, Rogers and Sharp, 2015) as the researcher approached an organization working with design and development of VR-applications, which the she was already in touch with. The organization was positive and highly interested in doing such an evaluation as well as participating in the interviews prior and following the evaluation.

3.3.1 Heuristic evaluation

The evaluation was conducted on a running VR-application. The application have been designed and developed by the participating organization for a significantly period of time and is subject to continuously improvements and development. For the evaluation a setup with an HMD connected to a laptop was utilized.

The heuristic evaluation in this study consisted of the following steps:

- heuristic evaluation and the heuristic set was presented to the evaluators individually,
- the evaluators individually evaluated the UI,
- the evaluators gave the issues found a severity rating (individually),
- a debriefing session where the evaluators and researcher discussed the issues found.

Presentation of heuristics

A presentation of heuristic evaluation and the heuristics was given to the participants individually by the researcher prior to the evaluation. The participants were then given time to read through the heuristic set they were using during the evaluation, and given the opportunity to ask questions about the method. Together with both participants, a user task was chosen to guide the evaluation, so that the two participants evaluated the same part of the UI. The chosen task was short, due to the limited time available for the evaluation.

The evaluation

The heuristic evaluation normally includes the evaluator going through the UI twice as part of the evaluating step. The first pass through the UI is intended to familiarize the evaluator with the interface they are evaluating, and the second pass consists of the evaluator judging whether there are any issues violating the heuristics. As both participants in this evaluation work continuously with this UI, the first pass was skipped.

The evaluators worked their way through the chosen task one time for each heuristic. This have been suggested (Nielsen, 1994b) as a possible variation of the heuristic evaluation method, although Nielsen notes that this will probably take significantly more time. However, it is advisable that evaluators have the heuristics available and visible during the evaluation in order to keep the heuristics in mind. In this particular study keeping the heuristics visible during the evaluation would be challenging, if not impossible, considering the evaluated UI is a functioning UI used with a HMD. Thus, the variation suggested by Nielsen where the evaluator go through the scenario focusing on one heuristic at the time, was considered more feasible for this study.

The researcher, acting as a moderator during the evaluation, read the heuristic out loud for the evaluators who would go through the task and consider if there were any issues violating that heuristic. Upon finding any issues they would state it out loud and the researcher would note the issues. This was repeated for all the heuristics used by that evaluator. The evaluators would then go over the issues they had found, noted by the researcher, and give each issue a severity rating.

Heuristic evaluation debriefing discussion

A debriefing discussion was done after the evaluation based on Nielsen's description of debriefing meeting (Nielsen, 1994b). The debriefing included both evaluators and the researcher. During the debriefing the issues found by each individual evaluator were discussed as well as the severity ratings given to the issues. This discussion enabled the two evaluators to gain an understanding of the other evaluator's rationale for noting the issues found and their reasoning behind their severity ratings. Further the discussion opened up for discussing possible ways of fixing the issues and what issues might be more reasonable to fix in a cost-benefit perspective.

3.3.2 Interviews with the evaluators

Interview exploring the design process

The unstructured interview investigating the design process was done with one of the participants of the heuristic evaluation. The participant described the design process and methods utilized by the organization when working on VRUIs for VR-applications.

The unstructured approach allowed the researcher to have the participant take the lead on what was important, in addition the researcher had the possibility of following up and asking relevant question as the conversation was flowing (Baxter and Courage, 2005). This approach was found highly suitable for this interview, which aimed to explore the participants design process as well as how they themselves articulated and described the process and what aspects of it they emphasized and focused on.

Interviews discussing the heuristic evaluation-method and heuristics

Directly following the heuristic evaluation, the researcher conducted a short individual, structured interview with the participant, where they would answer a set of statements (see Appendix 3). Their answers were being rated on a Likert-scale. The statements were read out loud by the researcher and were considered with their experience with the heuristic evaluation method and the heuristics used in the previous evaluation. A survey like this, a structured form of interview with answers on a Likert-scale are suitable for collecting data with predefined answers and measurements (Bryman, 2016).

A unstructured interview with both participants followed the individual, structured interview. The interview took form of open discussion where the researcher was concerned with exploring and learning about the participants recent experience with heuristic evaluation and the heuristics they had used.

3.3.3 Analysis of data from interviews with evaluators

Although the interviews before and after the heuristic evaluation were both unstructured, they had a narrow scope. The interview before the heuristic evaluation was concerning the organization's design process. This interview data was analysed and interpreted in connection to the results from the other interviews. The design process of the evaluator's

organization was compared to the design process described by the participants in the previous in order to investigate whether they uses a similar approach.

The data from the interview following the heuristic evaluation was concerned with the evaluator's attitudes towards the method and the heuristics. The data was analysed and interpreted in connection with the findings from the survey the evaluators answered directly after conducting the heuristic evaluation.

Data quality

The data from the unstructured interview before and following the heuristic evaluation have some limitations, as the interviews were only recorded in form of the researcher taking notes. The researcher noted during the interviews with a focus on content and meaning and not word by word.

A word by word recording of what is said by the participants in qualitative interviews are recommended, either by the researcher writing the responses exactly as they are expressed during interviews or by audio recordings. Such transcripts and recordings makes it easier for the researcher to go back and verify if she is uncertain about statements or meanings derived from the interviews (Leedy and Ormrod, 2014). The lack of such recordings might have implications for the validity of the study.

3.4 Ethical considerations

Important ethical issues in research is often concerned with protecting participants from harm, ensuring participants are informed and that they give consent voluntarily, and that researchers are honest in reporting their findings (Leedy and Ormrod, 2014). The researcher sought to keep a high standard in regards to all of these aspects.

Acting objectively and without bias

During the interviews, the researcher aimed to approach all participants and data objectively and without bias to the best of her abilities. The researcher worked towards this aim throughout the whole process.

3.4.1 Consent and treatment of personal information

Interviews with industry practitioners

A combined information letter and consent form were given to the participants prior to the interviews, either electronically or on paper (see Appendix 4). The information letter informed participants about the objectives of the study, how their information would be used in the study and the thesis report, as well as their rights regarding their personal information.

Personal information in this study is anonymized so that the data from the interviews cannot be traced back to the participants. However, the participants could choose to opt in to have their name included in the report in the *Acknowledgements* section. As the study used interviews with participants that could be personally identified, the study and the

planned use of personal information was reported to and approved by *NSD AS – Norsk senter for forskningsdata* (www.nsd.no).

Interviews with evaluators before and after heuristic evaluation

Consent from the participants were given orally by both participants prior to the interviews, and heuristic evaluation. Additionally the researcher described how the data collected would be used in the thesis report. No personal information was being collected in this activity and as previously mentioned, no recordings of the interviews were done.

4 Results

4.1 Insights from interviews

A total of 6 industry practitioners, all currently working, or previously been working, with design and development of applications for Virtual Reality (VR) participated in semi-structured interviews. The interviews aimed to gain insight into their design process and methods. Further, one objective of the interviews were to explore whether or not the practitioners had utilized heuristic evaluation and heuristics in their design process, either general purpose heuristics such as those by Nielsen (1994b), or heuristics specific for VR.

The interview selection indicates that industry practitioners have a wide range of educational backgrounds as well as holding highly different job titles and roles. However, all participants describe working, some full time and some on a project-basis, with design and development of Virtual Reality User Interfaces (VRUIs).

Only one of the participants calls oneself a designer and only one additional participant adds UX/UI-design when describing their job title and role. This might indicate a lack of designers working with design and development of VRUIs. Several participants mentioned having UX-designers on their team, either consistently or on occasion, however, despite efforts towards locating more designers, the researcher was not able to recruit more designers for the interviews.

Despite some challenges with locating participants for the interviews, in particular designers, all of the interviewed participants were positive towards participating in the interviews and in the study. They also showed a great deal of excitement and engagement in describing their design process and issues with VRUIs.

ID	**Job title/role**	**Field of education**
P1	Director, project manager and business developer	Media and communication, animation and games
P2	Chief strategy officer	N/A
P3	Graphic designer	Graphic design
P4	Business developer	Innovation and entrepreneurship
P5	Department manager	Computing and IT
P6	Digital artist (UX/UI-design, 3D-modeling)	Virtual art and design, VR and AR

Table 4.1: Participants in the interviews showing job title/roles and field of education

Prior to the personal interviews, the participants answered a questionnaire regarding their background and experience. Their answers, as visualized in *Figure 5.1*, indicate that many practitioners only recently started working with VR, half of the practitioners reporting having worked within the field for between 6 months-1 year, and only one reporting more than five years of experience. This resonates closely with what one participant described later in the personal interview, that there are few practitioners with extensive experience yet, as the industry as it is discussed in this study is fairly new and still emerging.

> And then we have UX-designers. But, there is no one who can wholeheartedly say that they are an experienced 3D-UX designer, the closest thing you got is UX-designers from gaming. – Industry practitioners

Further most practitioners in the study have some type of formal, higher education although, several report being self-taught to some extent, on much of the skills and knowledge needed for their work on VRUIS in the following personal interview.

Only one of the participants reported being familiar with, and having used heuristics and heuristic evaluation, confirming the researchers hypothesis that most industry practitioners are not familiar with the method, nor the heuristics. This participant described in the later personal interview, being familiar with both general purpose heuristics such as those N-1994 (Nielsen, 1994b) and VR-specific heuristics, as well as other types of design guidelines.

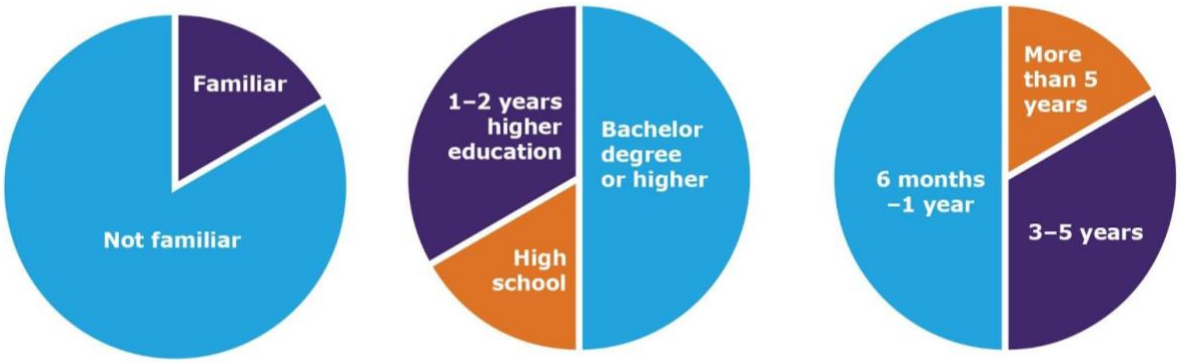


Figure 4.1: Participants familiarity with heuristic evaluation and heuristics, education level and time working with VR design and development, from left to right.

4.1.1 Central themes described by practitioners

The insights presented under the *design process* theme are about how the practitioners describe their process when working with design and development of VRUIs. It contains descriptions of methods utilized and what aspects of the process the practitioners put special emphasis on.

Under the *design guidance* theme are descriptions of lacking best practices and guidelines, as well as attitudes towards potential development of new and VR-specific design guidance. Additionally thoughts about experiences and experience with heuristics were discussed with the relevant participant.

VRUI design considerations includes descriptions of what practitioners see as particular important aspects to think of when designing for VRUIs such as user comfort, as well as aspects described as further challenging the design process of VRUIs such as a constant technological innovation.

Design Process	2D-HCI processes and methods	
	Involved fields of expertise	
	Process approach	
	Process steps	Iterative process
		Prototyping
		Requirements work
		Sketching
		User testing
Design guidance	Development of guidance	Application diversity
		Implications of innovation
	Emerging conventions	
	Guidance sources	
	Heuristics	
	Lack of guidance	
	Universal design	
VRUI Design considerations	No real experts	
	Technology implications	
	User considerations	Evolving users

		User comfort
	VR considerations	

Table 4.2: Codes used during data analysis of interviews

4.1.2 Design process

Different approaches to the overall design process was labelled by individual participants such as a User-Centred Design-process, a process based from AAA-gaming development and a process described as based on LEAN-methodology. Half of the participants did not label their process with a specific term.

The process and utilized methods described by the practitioners was highly similar regardless of the label put on the process and whether or not they labelled the overall design process at all.

Focus on development and technological implications

Several of the participants focused on describing the steps after programming and developing of the application was started, describing how they built the application and how user testing and iterations were done on the developed prototype. This might indicate and support claims that the VR-industry is highly technology driven and thus focus more on the development part of the process (Jerald, 2016).

One of the participants suggested that many practitioners working with VR might put a lot of thought and effort into how to develop a solution and what is possible to develop technologically, and less on what tasks and issues the solutions are aiming to solve. Further the participant suggested that the industry, and the usability of VR-applications, might benefit from a stronger focus on users and tasks instead of what is technologically feasible to build.

> It reminds me a bit of the first meeting between designers and developers working with websites...That you have to kind of… you need to take a step back and look at what is actually the purpose instead of developing just for the sake of development
> – Industry practitioner

4.1.3 Design guidance

Most of the participants describe a lack of design guidance suitable for VRUIs as well as few acknowledged conventions. Further participants describe what might be an expression of doubt towards if it is possible to develop guidelines and standards for VRUIs, and mention several aspects that might affect this development.

> As I mentioned, we don’t find much guidelines and best practices out there.
> – Industry practitioner

> Yes, I searched for it, but I didn’t find anything. Not anything useful anyway.
> – Industry practitioner

Although describing a lack of acknowledged conventions, the participants do describe some conventions that might be emerging such as teleporting for navigating a virtual environment, often used as a substitute instead of walking. One participant also mentioned an increased use of menus for system control placed on the controllers or hands of the users as a possible emerging convention.

One aspect mentioned by the practitioners, that possibly affects both availability of design guidance and conventions, are the broad variety of applications. In this, rather small, selection of industry practitioners a variety of different applications were described. These applications ranged from among other, complex virtual environments in the form of buildings and constructions, via data visualizations, to uncomplicated simulators for entertainment purposes.

The variety of applications and the possibilities within what can possibly be designed and developed, is described as a possible hindrance for conventions to emerge, and some participants have difficulties imagining an extensive development of conventions and standards.

> So, I have difficulties imagining that you can standardize something that can be everything.
> – Industry pracitioner

> And that is…, what can be suitable for one type of application, might not be suitable at all for another application
> – Industry practitioner

One described that a possible reason it might be difficult to develop design guidance is connected to the constant innovation in the industry, as noted under the theme *VR design considerations.* The practitioners express that it might not be feasible to develop guidelines and principles working with a technology constantly changing.

> Yes, and that means that what we know of interfaces today, is not valid in May.
> – Industry practitioner

> So I have tried finding guidelines to use, but those guidelines are not there yet, because no one knows what would be the right guidelines.
> – Industry practitioner

Only one of the interview participants had knowledge about, and was familiar with, heuristics and heuristic evaluation (Molich and Nielsen, 1990b, Nielsen, 1994b). This participant also described having utilized heuristic evaluation in the design and development process of VR-applications.

Further the participant emphasized that although heuristics might be a useful guidance, particularly for practitioners without much experience, that it had to be used in connection with rapid prototyping and user testing. The participant also shared the concerns of the other participants about challenges of developing heuristics and guidelines in an industry with constant technological innovation and a vast variety of applications.

The participant familiar with heuristics also described being familiar and utilizing other design guidance such as guidelines and principles from various authors on the subject. Other participants also mentioned some design guidance, but did not elaborate in detail how and if they were utilized in their process.

4.1.4 VR-specific design considerations

In the interviews participants were asked if there were any special considerations they saw as important when designing VRUIs, or if they encountered or experienced challenges specific to working with design and development of applications for VR.

The considerations included a high level of diversity among users, ranging from complete novices to more experienced, different types of hardware which all had characteristics that would have to be considered and issues such as users mental and physical comfort.

Finding a good balance, and catering to both novice and experienced users were described as a challenge by most practitioners. Some novice users who never have put on a HMD before, might need assistance with everything from putting the headset on, to using the controllers, where a more experienced user might require more alternatives for more flexible use in order to not get bored or impatient.

> Yes, and some of them are bored because they are so smart, and some of them are bored because they don't understand. So you need an interface that is both fast and slow
> – Industry practitioner

> ...finding a good balance, between those who are complete novices and the ones with a bit more expertise, that is always a challenge
> – Industry practitioner

Making sure users are comfortable in using their applications was described by all participants as an important and challenging design consideration. User comfort includes making the users feel safe and in control, and that users will not experience motion sickness, sometimes referred to as cybersickness.

> The first, most important and most complicated, is motion sickness
> – Industry practitioner

> *That it is comfortable, that people will not get sick by using it. That, is not a problem you usually need to consider when working with 2D-systems at all, but with 3D you need to consider that, a lot.*
> – Industry practitioner

> *And then, how comfortable is the experience, do you get sick?*
> – Industry practitioner

Further participants described that the overall tolerance level for annoying things such as the application not working as the users expect them to, or the user not being able to complete the tasks as they expect to. They report that there is less room for irritation before users give up and take the HMD off, which might prevent users from completing the tasks they initially wanted to do.

4.2 Literature Review: Usability Heuristics for VRUIs

The objectives of the literature review was to explore and uncover usability heuristics available through the research literature. Further the review aimed to in some extent explore how these heuristics were utilized and evaluated. The review utilized a systematic

search approach including pre-defined criteria for exclusion and inclusion as well as a well defined search strategy in order to reveal usability heuristics.

4.2.1 Heuristics included for further investigation

Search 1 & 2 from Scopus (after eliminating duplicates)	25
Search 1 & 2 from Web of Science (after eliminating duplicates)	27
Total search 1 & 2 from both databases	52
Total search 1 & 2 after eliminating duplicates	35
Excluded articles based on exclusion criteria	33
Articles left for review	2
Article found and included through following lead	1
Total articles reviewed	**3**

Table 4.3: Results from the literature search

The findings from this literature review suggest that there are still few heuristic sets specifically created for VRUIs available through the research literature. Through the initial literature search, two heuristic sets were found, a heuristic set for VR-applications (Gault and Sutcliffe, 2004); S-2004, and a set of heuristics for Virtual Reality Systems (Murtza, Monroe and Youmans, 2017)**;** M-2017.

A third set of heuristics, for Virtual Worlds (Rusu *et al.*, 2011); R-2011 was found by following a lead in one of the studies (not included in the review) from the literature search, who had used the heuristics in a comparison study (Oliveira**,** Simoes and Correia**,** 2017). Although not initially developed for use with VRUIs, it is included in this study as it was used in an study comparing R-2011 to S-2004 in evaluating games for low-cost VR such as Google Cardboard (www.vr.google.com/cardboard).

The S-2004 heuristics are, similar to the R-2011, not developed specifically with HMD-based VRUIs in mind, as it was initially evaluated in an experiment evaluating CAVE systems. However, as the authors suggests they might well be suited for HMD VRUIs as well, and is used in among others, the above study (Oliveira, Simoes and Correia, 2017) they were included for further investigation.

A fourth set of heuristics were uncovered in the literature search in addition to the three sets mentioned above, through using the secondary search string. This heuristic set was specifically developed for VR Learning Applications (Harrington, 2006). Additionally, among the results in the literature search was studies defining and presenting heuristics on specific aspects of VR, such gestural interaction (Chuan, Sivaji and Ahmad, 2015) and 3D GUIs (Kaur and Yammiyavar, 2017). However, as this review focused on general purpose heuristics for VRUIs, these were not included for further investigation

This leaves three sets of heuristics to be investigated further in this review:

- S-2004 (Gault and Sutcliffe, 2004)

- R-2011 (Rusu *et al.*, 2011)
- M-2017 (Murtza, Monroe and Youmans, 2017)

Below the development process of these heuristic sets, the author's stated objectives with the heuristics and their intended use will be discussed. Additionally the utilization of the heuristics will be somewhat explored.

4.2.2 Usability Heuristics for Virtual Applications

Presenting 12 heuristics for heuristic evaluation of VR-applications, (Gault and Sutcliffe, 2004) state they are likely to be the first in the VR-HCI research field to develop such as set of heuristics. They acknowledge that researchers before them have proposed heuristics for this type of evaluation before, but suggest that these mainly consists of adaptations of Nielsen's heuristics (Nielsen, 1994b)

Some of the author's reasoning behind the heuristic, are that they suggest previous studies show need for more efforts towards improvement of usability in VRUIs, as well as the authors claiming that practitioners working with VRUIs lack extensive HCI-knowledge.

S-2004 are reported to be derived by Nielsen's heuristics (Nielsen, 1994b), from now referred to as N-1994. Further the authors describe utilizing previous work on design principles for VR (Sutcliffe and Kaur, 2000) in their work with this heuristic set. The development process of the heuristics are not described in further detail.

The researchers also added another aspect to the originally proposed heuristic evaluation method (Molich and Nielsen, 1990b, Nielsen, 1994b) which they describe as a *tech audit,* intended to prepare evaluators whom might be unfamiliar with VR-applications for the evaluation.

S-2004, the first to be published of the heuristics sets found, have a significantly higher citation count than the two newer ones in both databases used for the review. This could partly be related to S-2004 being available for a longer period of time.

In a study evaluating how the S-2004 heuristics were utilized the authors noted that the publications who had cited these heuristics often used them in parts, and not necessarily as a complete set of heuristics. They further suggested a patchwork approach to heuristics, where practitioners can choose from different categories of heuristics to suit their needs rather than complete heuristic sets. Furthermore they found some of the citations to be publications only discussing the heuristics, rather than using them in experiments or as part of the design process (Hvannberg, Halldorsdottir and Rudinsky, 2012). A study choosing and utilizing only the sets VR-specific heuristics on presence and intuitive interaction was found in this review. The study used the heuristics in combination with heuristics from N-1994 (Altarteer *et al.*, 2017).

ID	Name	Description
1	Natural engagement	Interaction should approach the user's expectation of interaction in the real world as far as possible. Ideally, the user should be unaware that the reality is virtual. Interpreting this heuristic will depend on the naturalness requirement and the user's sense of presence and engagement.
2	Compatibility with the user's task and domain	The VE and behaviour of objects should correspond as closely as possible to the user's expectation of real world objects; their behaviour; and affordances for task action.
3	Natural expression of action	The representation of the self/presence in the VE should allow the user to act and explore in a natural manner and not restrict normal physical actions. This design quality may be limited by the available devices. If haptic feedback is absent, natural expression inevitably suffers.
4	Close coordination of action and representation	The representation of the self/ presence and behaviour manifest in the VE should be faithful to the user's actions. Response time between user movement and update of the VE display should be less than 200 ms to avoid motion sickness problems.
5	Realistic feedback	The effect of the user's actions on virtual world objects should be immediately visible and conform to the laws of physics and the user's perceptual expectations.
6	Faithful viewpoints	The visual representation of the virtual world should map to the user's normal perception, and the viewpoint change by head movement should be rendered without delay
7	Navigation and orientation support	The users should always be able to find where they are in the VE and return to known, preset positions. Unnatural actions such as fly-through surfaces may help but these have to be judged in a trade-off with naturalness (see heuristics 1 and 2).
8	Clear entry and exit points	The means of entering and exiting from a virtual world should be clearly communicated.
9	Consistent departures	When design compromises are used they should be consistent and clearly marked, e.g. cross-modal substitution and power actionsfor navigation.
10	Support for learning	Active objects should be cued and if necessary explain themselves to promote learning of VEs
11	Clear turn-taking	Where system initiative is used it should be clearly signalled and conventions established for turn-taking
12	Sense of presence	The user's perception of engagement and being in a 'real' world should be as natural as possible

Table 4.4: Usability heuristics for VR-applications (Gault and Sutcliffe, 2004)

4.2.3 Usability heuristics for virtual worlds

The R-2011 heuristic set (Rusu *et al.*, 2011), although included in this review is not initially intended for HMD-based VR such as this study is mainly concerned with, nor CAVE-types of VR. The authors have not stated whether or not they assume these heuristics to be applicable for these types of VR. However, as one of the studies found through the review have utilized these heuristics and compared them to S-2004 in evaluating of VR games utilizing HMDs, the heuristic set is briefly investigated.

The authors report utilizing a specific methodology for developing new usability heuristics (the researcher was unable to follow and find the cited article) described methodology to include the following stages: 1: exploratory, 2: descriptive, 3: correlational, 4: explicative, 5: validation and 6: refinement. The cited methodology is similar to a methodology published later, which cite the same article as the authors of R-2011 (Quinones, Rusu and Rusu, 2018).

Number	**Heuristic Name**	**Heuristic Description**
Design and Aesthetics group		
1	Feedback	A VW interface should keep user informed on both avatar's state, and the relevant facts and events that affect him.
2	Clarity	A VW should offer an easy to understand user control panel, using clear graphic elements, text and language, grouping elements by their purposes, and offering easy access to the main functionality.
3	Simplicity	A VW should provide easy and intuitive interaction with the environment's virtual objects. Only relevant information should be given, in order to avoid the control panel's overload.
4	Consistency	A VW should be consistent in using language and concepts. Avatar's actions and their effects on the VW's environment should be coherent and consistent. User – avatar, as well as avatar – VW's objects, should be consistent.
Control and navigation		
5	Low memory load	A VW should maintain main objects, options, elements and actions always available or easy to get to. It should provide ways to mark and remember places already visited and/or of user's interest.
6	Flexibility and efficiency of use	A VW should provide customizable shortcuts, abbreviations, accessibility keys or command lines. The user interface/control panel should be customizable
7	Camera control	A VW should give user control over camera, allowing a customizable user's view
8	Visualization	A VW should give user control over the objects and visual effects that he/she will get visible.
9	Avatar's customization	A VW should allow fully avatars' customization.

10	Orientation and navigation	A VW should provide full (customizable) information on avatar's position, paths to a desired destination, and passage ways from one position to another (according to VW's rules).
11	World interaction	A VW should clearly indicate the objects that user may interact with, as well as the actions that user may perform over the objects
12	World's rules	A VW should clearly indicate its own rules and the rules that govern avatars, especially the actions that are impossible in the real (user's) world, but are possible in the VW (and vice versa).
13	Communication between avatars	A VW should allow easy communication among users, through their avatars.
Errors and help		
14	Error prevention	A VW should prevent users from performing actions that could lead to errors, and should avoid confusions that could lead to mistakes, during user – control panel interaction, as well as during (user's) avatar – VW interaction.
15	Recovering from errors	A VW should provide user appropriate mechanisms to recover from errors, and exit ways from unwanted situations. It should include clear messages, hopefully indicating causes and solutions for errors
16	Help and documentation	A VW should provide an easy to find, easy to understand, and complete online documentation, accessible from both inside and outside of the world itself.

Table 4.5: Usability heuristics for virtual worlds (Rusu *et al.*, 2011)

4.2.4 Usability heuristics for VR-systems

The most recent published set of heuristic is M-2017 (Murtza, Monroe and Youmans, 2017). Development of the heuristics builds on surveys of VR-system users, and quotes from the survey respondents links directly to the heuristics as they are used to help explain the meaning of the heuristics.

The authors does not discuss any other heuristic sets previously developed for VR such as S-2004 in this study.

M-2017 is the only one of the heuristics in this review that is specifically developed for HMD-based VR. The heuristics aims to address both issues in VR software and also VR hardware, as the authors suggest that the hardware have a potential implication on the usability of VR applications.

The set consists of only 9 heuristics, however, for user interface concerns it references N-1994 as suitable guidelines to use. This means that the total number of heuristics, if one should follow the authors advice, will be 19 heuristics.

ID	**Name**	**Description**
1	Synchronous Body Movements	The system and interface should stay in synchrony with human head & body movement in real time to prevent lag.

2	Physical Space Constraints	The system should account for the real-world physical space users' occupy when interacting with the system.
3	Immersion	The system should immerse the user in virtual reality, specific to visual realism.
4	Glitchiness	The system should promote a streamlined experience by keeping systematic glitches low.
5	Switch between real and virtual world.	The system should be able to rely on itself for all usage; that is, keep all necessary user tasks and information within VR, instead of creating tasks that the user may only be able to execute when VR headset is taken off or information that can only be accessed by taking headset off.
6	Cord Design.	The cord of the system should be designed such that VR usage requires minimal maintenance, e.g. providing adequate length and mobility to keep entanglement to a minimum.
7	Headset Comfort	The headset of the system should be designed to be comfortable for prolonged wear
8	Mental Comfort	The system should be designed to prevent sensations of physical illness during use, by preventing jarring movement lag, increasing realism of visuals, and so on.
9	User Interface Design.	The system's interface and hardware controls should have a intuitive design and navigation, adhering to usability conventions

Table 4.6: Usability heuristics for Virtual Reality Systems (Murtza, Monroe and Youmans, 2017)

4.2.5 Similarities among the heuristic sets

S-2004 and M-2017 are the two sets among the three investigated in this review most similar to each other. Both S-2004 and R-2011 however, are closely connected to N-1994). The authors clearly state the connection between R-2011 and N-1994 in showing how the heuristics are all represented by one or more of the heuristics in R-2011.

M-2017 is closely connected to N-1994 as the authors are suggesting practitioners utilize these heuristics for a closer evaluation of the user interface design. The first 8 heuristics of M-2017 on the other hand, are to a large extent concerned with what can be seen as hardware-factors and thus not that closely connected to N-1994.

S-2004 and M-2017 bear similarities of both being concerned with immersion: S-2004 specifically through heuristics 1, 3 and 12 and M-2017 in heuristic 3. R-2011 does not mention immersion, this might be understandable as the R-2011 is intended for the use with virtual worlds, mainly in a desktop setting.

4.3 Results of heuristic evaluation and insights from interviews

The objectives of this part of the study included testing the heuristic evaluation with industry practitioners unfamiliar with the method in a realistic and practical context. Additionally an interview prior to the heuristic evaluation aimed to investigate the

evaluators design process, and an interview with both evaluators after the evaluation aimed to explore the evaluators attitudes towards the method.

4.3.1 Insights on the design process

Through the interview with one of the evaluators prior to the heuristic evaluation, the researcher was able to investigate into greater detail the design process used by the team the two evaluators were a part of. The process was similar to the process described by the industry participants in the previous interviews (see section 4.1 and 4.1.2).

The evaluator described, similar to the participants in the previous interviews, utilizing sketching techniques both in designing alternatives and as points of discussion with clients. Further the evaluator described an emphasis on early, rapid and continuous prototyping including testing and evaluating the application along the way with end-users, the client, and with colleagues.

In this interview it was possible to explore areas of the design process which the researcher was not able to investigate in the previous interviews such as the how the evaluator described working with gathering and establishing requirements. Described was conversations and workshops with the client, utilizing matrixes for describing business goals as well as what the client and the team know of the current situation and the users the application was aimed towards. Further the evaluator described mapping the user journey in a detailed way in form of a list all functions in the application.

4.3.2 Results of heuristic evaluation

Two participants tested the same interface and same scenario with different sets of heuristics, Evaluator 1 used N-1994 and Evaluator 2 used S-2004. The evaluators both followed the same evaluation steps (see 3.3.1). The evaluation for both evaluators took about 20–30 minutes. In that regard it should be noted that the evaluators evaluated a task flow that was quite limited.

Heuristic set	**Total number of issues**	**Average severity rating**
N-1994	4	2.25
S-2004	14	2.42

Table 4.7: Number of issues found by the heuristic evaluations

There is a significant higher number of detected issues from the evaluation using S-2004 compared to the evaluation using N-1994. However, there were only two evaluators participating in this evaluation and so the reliability of this comparison must be said to be low, this is discussed further in the discussions chapter.

The difference amount of issues reported by the evaluators might be caused by several factors. Firstly evaluators utilized two different sets of heuristics that possibly caused the variation in the amount of issues found. The argument for utilizing a specific set of heuristics is that it will be more efficient than general purpose heuristics, as is the case of S-2004 (Gault and Sutcliffe, 2004) which was compared towards N-1994 (Nielsen, 1994b). This study also compared N-1994 with S-2004, although in a small scale comparison.

Furthermore the evaluators were holding two, somewhat different, positions in the design team and process, which might also have made one of them more inclined to note problems and the other more hesitant (one was more tasked with "fixing problems", the other working on a more holistic/broader level). The evaluators themselves did not see this difference between evaluators as a particular drawback of the method, but rather saw it as a possible starting point for discussions around possible improvements in an application.

4.3.3 Attitudes towards heuristic evaluation and heuristics

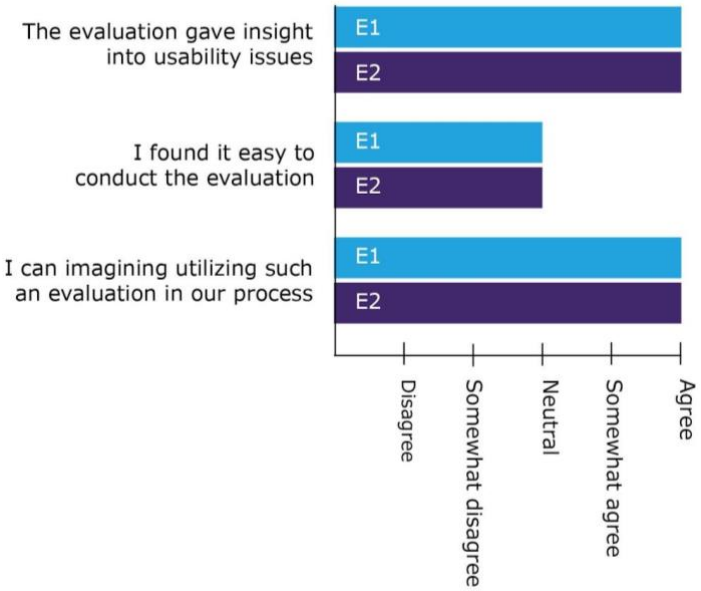


Figure 4.2: The evaluator's reported attitudes towards heuristic evaluation as a method

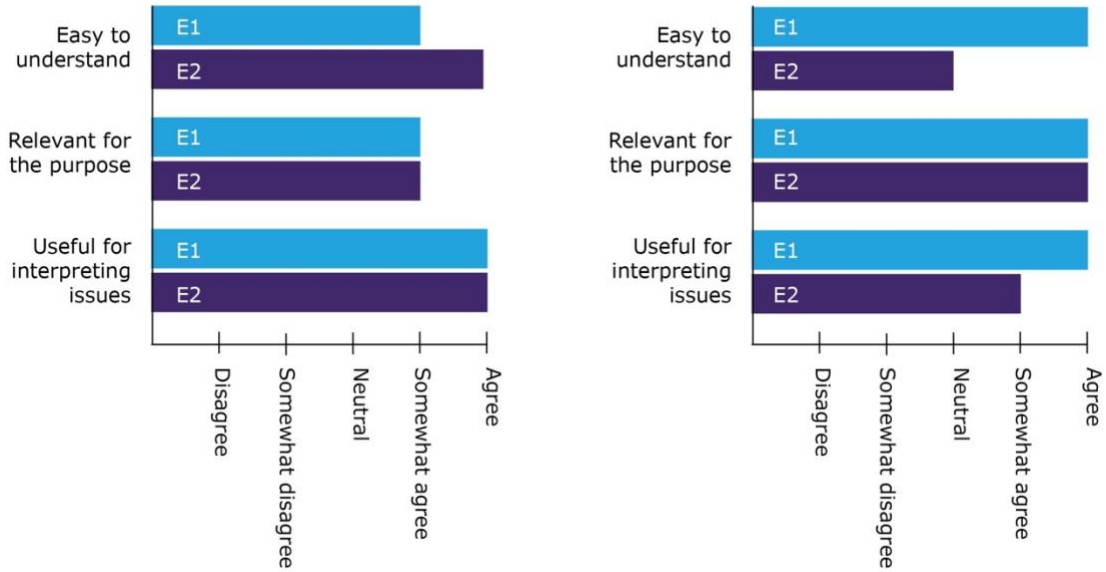


Figure 4.3: The evaluators reported attitudes towards the heuristics used in evaluation N-1994 to the left (Nielsen, 1994b) and S-2004 to the right (Gault and Sutcliffe, 2004)

As shown on *Figure 4.2*, both evaluators found the heuristic evaluation method to be a possibly useful method in their own design and evaluation process. The neutral score on in regarding how easy the method was to use might be caused by this being the first time doing such an evaluation for both evaluators.

As shown on *Figure 4.3* attitudes towards the heuristic sets are quite similar, although S-2004 can be seen to have a slightly higher average score. Overall both evaluators seem to find the heuristics fairly easy to understand and use, as well as finding both sets to be quite useful in interpreting issues.

Both evaluators suggest that the method can be a good alternative to in-office testing, describing that they often test the application on themselves, colleagues or others in the office environment. They suggested that the heuristic evaluation gives them a slightly different focus, putting them into a *"user test"*-mode

4.4 Summary of results

The design process

Most industry practitioners described utilizing a similar design process, although not necessarily labeling it the same or labeling it at all. They put much emphasis on the importance of user testing, and described efforts towards testing their applications frequently, although this testing varied from evaluations with end-users to conducting in-office user tests on colleagues and team members. Further they highlighted that VRUIs required rapid prototyping and more frequent iterations in addition to user testing.

The process described by the industry practitioners in the interviews, to a large extent aligned with the process described by one of the industry practitioners doing he heuristic evaluation, although the researcher in the interview with the evaluator prior to the heuristic evaluation managed to reveal some more details about how their organization worked with user requirements.

Practitioners describe several design considerations they find important to consider when designing and developing VRUIs. Among these considerations are ensuring user comfort, and facilitating for ease of use as well as efficient use for both novice and more experienced users. Further practitioners describe the constant innovation in the industry as well as a significant variety in available hardware as potential challenges, although the constant innovation also in sometimes are described as exciting and promising in terms of the opportunities technological advances might present.

Design guidance

Most of the industry practitioners describe a lack of, and indicate a possible need for, design guidance in their field, although they also expressed some doubts towards whether the development of such guidance was feasible. This doubt seems to be caused by constant innovation, which leads to that things that are impossible to implement today might be possible tomorrow, and the participants express that it might be difficult to develop guidance when everything is always changing. Additionally they describe a large variety in applications which might require different approaches, as well as differences in hardware possibly complicating both the development of design guidance and conventions.

Heuristics and heuristic evaluation

Only one of the practitioners in the interviews were familiar with heuristic evaluation and heuristic, and the evaluators in the heuristic evaluation, were both unfamiliar with the method and this type of design guidance (heuristics).

S-2004 is the one set that is developed with the objective of providing specific heuristics for the VR-community. It has been available for a significant period of time and thus is the one heuristic set by the three investigated that have been utilized the most. The review found that both R-2011 and M-2017 had not yet been utilized in a large number of studies.

Some studies indicate that the S-2004 is more likely to be utilized by researchers and practitioners through using one or more individual heuristics from the set suited to their purpose, instead of utilizing the set as a whole. Accordingly they suggest a model where researchers and practitioners might pick single heuristics from different sets, suited to the individual project (Hvannberg, Halldorsdottir and Rudinsky, 2012).

The evaluators doing the heuristic evaluation had positive attitudes towards the method and both utilized sets of heuristics. The result from the heuristic evaluation was similar to the results from the authors of S-2004, finding that S-2004 revealed more issues than N-1994.

In the next chapter the researcher reflect on these findings and discuss what place heuristic evaluation and heuristics might have in a VR design and evaluation process. Before reflecting and discussing the findings the researcher will present a reflection on the research process as well as the chosen methods utilized in the study.

5 Discussion

In this section the researcher provide reflections on the research process as well as the utilized methods. Following is a discussion of insights from the interviews with industry practitioners, before the researcher moves on to discuss usability heuristics for, and heuristic evaluation on, VRUIs. The chapter ends with a summary and some concluding comments, as well as a reflection on the contributions of the study and potential topics for further work.

5.1 Reflections on the process

The initial research plan involved a process that would take one step at the time, beginning with the literature review, moving on to the interviews before conducting and experiment exploring the efficiency of usability heuristics and heuristic evaluation.

The intention was that each step would build on the previous one. However, a research process is rarely linear, and can often be seen more as an iterative process (Bryman, 2016, Leedy and Ormrod, 2014). This was also the case of this study and this became evident early in the process.

As the research project progressed and the iterative nature of research became clear for the researcher, the approach was adjusted, opening up for more flexibility. The literature and interviews were done more in parallel, allowing for data from the interviews to inform the literature review during the process. Instead of the process consisting of three different steps, the process can be seen as two phases, where the first phase informed the second phase.

Initially the researcher planned an experiment aimed to compare the efficiency of general purpose heuristic with VR-specific heuristics, as well as the method itself. However, after learning about industry practitioners design process from the interviews and reading more about the academic research in the field the this plan was adjusted in order to follow up on the insights gained.

After the interviews with practitioners and conducting the literature review, the researcher found it more appropriate, to rather than comparing the efficiency of different heuristics, explore heuristic evaluation and heuristics in a practical context together with industry practitioners. The objective was to explore the feasibility of the method in such a context, and to explore the attitudes of the practitioners who were unfamiliar with the methods, towards the method and utilized heuristics.

5.2 Reflections on the chosen methodology

5.2.1 Interviews

Recruiting participants for the interviews proved to be a time consuming challenge, particularly reaching interaction/UX/UI-designers working with VRUIs. However, all participants in the interview selection showed positive attitude towards participating and towards the study.

Despite extensive effort towards locating interaction/UX/UI-designers the researcher did not find anyone who worked mainly with VRUIs. This might be caused by the researcher not having extensive knowledge about the industry, so that she did not know where to look. It might also be that there is not a large amount of designers working in the industry, and this is somewhat supported by descriptions from the participants themselves.

The interviews with the practitioners were semi-structured. The researcher chose this approach as there was some uncertainties towards who the interview participants would be as, practitioners in the VR industry have a large range of different backgrounds and skills. This is also reflected in the interview selection.

The semi-structured approach served the researchers aims well as it allowed for flexibility in the conversations with the industry practitioners. As the objective of the interviews were highly explorative in aiming to learn about the practitioners design process the flexible approach left room for the researcher to explore and learn, while ensuring to visit and discuss key aspects important for the study.

Acting without bias and without having any effect on the participants in an interview and in a study as a whole is challenging and it requires significant practice in order for anyone to become a skilled interviewer or researcher (Baxter and Courage, 2005). As this is the researcher's first major research project, she is still learning. Conducting a pilot interview, as well as listening to recordings from the interviews was particularly helpful in aiding the learning process of becoming a more skilled interviewer and researcher.

5.2.2 Literature review

In the literature review the researcher sought to take a systematic approach. Implementing this in a master thesis research project might be not be entirely feasible, as such an approach commonly is quite extensive as well as involving several aspect which can be challenging in such a study with limited resources (Bryman, 2016).

The study implemented a detailed and pre-defined search strategy which is documented in the report. The objective of this transparency is to make the review possible for other researchers to recreate, so that the results more easily can be compared.

As this study have a limited timeline, being part of a master thesis research project, the researcher found it reasonable to plan the scope of the review to be quite narrow, although systematic reviews commonly are more extensive. This proved to be a good plan, as the review in its narrow scope, still proved to be time consuming to complete. If the study had a longer timeline, the scope of the review might have been successfully broadened. In case of a longer timeline, more resources might also be available and thus might make room for incorporating more characteristics of a systematic review such as several reviewers. However, for the objectives of this study, the planned and narrow scope provided the researcher with the insight she needed to continue with the rest of the study.

5.2.3 Heuristic evaluation

The heuristic evaluation explored the attitudes of the industry practitioners towards heuristic evaluation and heuristics, and whether they found the method as potentially useful and feasible to implement in their own process.

The heuristic evaluation was conducted with only two evaluators in the same organization. Accordingly the validity of these results are quite limited due to the small selection. However, the heuristic evaluation itself and the following group interview was highly informative. It was also an activity that could easily be recreated in another organization and with several evaluators. Thus the researcher believes it could be both useful and feasible to scale this activity up and that way collect more valid data. This have also been done in other studies (Gault and Sutcliffe, 2004, Oliveira, Simoes and Correia, 2017).

As with the interviews the researcher aimed to be objective throughout the whole process. However, the researcher in retrospect finds that in particular the survey measuring the evaluators attitudes towards heuristic evaluation and the heuristics utilized included mostly positively worded statements. This might have influenced the

evaluators answers. Including some more neutrally and negatively worded statements might have increased the quality of these results.

The data from the interviews both prior and following the heuristic evaluation have some limitations of quality as they were not audio recorded and thus not transcribed word by word. This was due limited time for the researcher to plan the heuristic evaluation and interviews as well as the researcher lacking experience. Ideally the interviews would have been audio recorded. However, it should be noted that the interviews took form of highly informal and open conversations and discussion and this might have been implicated of the researcher audio-recording the conversation.

5.3 Discussion of insights from the interviews

The interviews explored whether or not industry practitioners had utilized VR-specific heuristics and heuristic evaluation in their design process and further if they had utilized other usability heuristics and principles. Additionally the interviews explored the design process and methods utilized by the industry practitioners (see 1.2.1)

The findings revealed that few (only one) of the industry practitioners, both in the interviews and the practitioners participating as evaluators in the heuristic evaluation, had implemented VR-specific usability heuristics in their process. This confirms the researcher hypothesis (H1, see 1.2.1).

This might indicate that the practitioners are not aware of the research efforts done in the field. It might be suggested that they could have found heuristics and heuristic evaluation unsuitable for their purpose. However, as most practitioners also describe a general lack of design guidance, and that some sort of design guidance could be helpful, it might be more reasonable to believe that the research literature has not reached the industry yet, something that also was suggested by the one practitioner who had experience with heuristic evaluation and heuristics.

The interviews also sought to explore the industry practitioners design process and the methods they utilize. Most of the participants do not seem to have a term or label for their design process. However, the design process they describe in many ways resemble a UCD-process. One participant also used UCD-process as a term to describe the design process utilized by the team the participant were a part of. The evaluators participating in the heuristic evaluation also describe a design process similar to that of the industry practitioners in the interviews.

All participant described a process which in most ways follow the principles of UCD (Gould and Lewis, 1985). They emphasize that a highly iterative process is essential for design and development of VR-applications. Further they emphasize the importance of user testing.

What practitioners do not describe as thoroughly, is how and if they implement users early in the process, which is one of the principles of UCD. The researcher managed to investigate this further in the interview with one of the evaluators prior to the heuristic evaluation, which revealed that the industry practitioners in that organization did consider the users and the users tasks early in the process.

As the process described by the evaluators and the industry practitioners in the previous interviews have been quite similar in all other aspects, it might be reasonable to think that most of the industry practitioners utilize similar methods, and have a similar focus on users and tasks early on. One possible cause of the researcher being unable to obtain descriptions of this in the previous interviews might be the that interviewees and researcher have different backgrounds and thus use different terms and have a different point of view in the context of a design process.

5.4 Heuristic evaluation and heuristics in VRUIs

The literature review found three heuristics sets specifically for VR. One of these, R-2011 (Rusu *et al.*, 2011) was developed for virtual worlds, and was only included as it was used in a study evaluating VR games (Oliveira, Simoes and Correia, 2017). However,

after further inspection the heuristic seems unsuitable for VRUIs in addition to the authors not addressing VR in the study presenting the heuristics. This leaves only two sets specifically for VR.

The most recent one of these two, M-2017 (Murtza, Monroe and Youmans, 2017) have not been utilized as the reviewer can find, at the time of the review. This might be caused by the heuristic set's recent publication date and does not necessarily reflect the quality of heuristics. M-2017 is the only set of the heuristic sets aimed towards HMD-based VR.

The first to be published by the sets investigated in the review, S-2004 (Gault and Sutcliffe, 2004), was not initially aimed towards HMD-based VR. The authors of the set however, suggest the set might also be suitable for this type of VR.

As S-2004 was the most utilized set by the three found in the review, and M-2017 additionally did not address UI directly but rather references N-1994 (Nielsen, 1994b) this heuristic set was chosen to be utilized in the heuristic evaluation with industry practitioners.

The results of the heuristic evaluation favoured S-2004 compared to N-1994 as the most effective. However, the findings also show that the evaluators focused on different aspects of the interface during the evaluation which might be part of the reason why one set performed better than the other. Additionally the two different evaluators might have different motivation towards report issues, meaning that one might be more inclined to report more issues than the other. Furthermore, the study's limited scope makes it challenging to come to any conclusion about the effectiveness of the two different sets, nor was that the objective of the study.

The evaluators described and showed a positive attitude towards the method and the heuristics. Although one of the heuristic sets revealed significantly more issues than the other the evaluators reported finding both sets useful and relevant, suggesting the different sets might be suitable for different parts of the interface. When the researcher brought up the possibility of rather than choosing one heuristic set, evaluators could choose heuristics from several sets as suggest by one study (Hvannberg, Halldorsdottir and Rudinsky, 2012), the evaluators were positive to the suggestion.

Potential differences in reported issues between evaluators did not seem to worry the evaluators, rather they suggested variations in reported issues could be a useful point of discussing possible improvements for the interface. Further the evaluators expressed that user testing would still be needed, but that the evaluation might be a helpful supplement. This is in line with what the industry practitioner in the previous interviews, having experience with the method, suggested, that heuristic evaluation might very well be useful in a VR design and development process, but that it would need to be used in connection with user testing and rapid iterations.

5.5 Summary and concluding comments

It is challenging to draw any conclusions as all of the research questions, and the study as a whole is highly explorative, making it difficult to be conclusive. However, the study can conclude, that the researcher's hypothesis (H1, see 1.2.1) that most practitioners are unfamiliar with heuristic evaluation and heuristics is confirmed. Although one of the participants reported having experience with the method and different sets of heuristics, that participant stated having a special interest into this field of research, indicating that this might not be common among industry practitioners.

It might be useful for industry practitioners to test utilizing heuristic evaluations into their own design processes, as the findings suggest the method might have a potential of contributing to improvements in VRUIs. However, the method is not perfect, and the researcher would like to emphasize that there are no findings indicating that such a method should be utilized on the behalf of, or instead of iterative user testing. Additionally this study is a small scale study, and further work is needed in order to conclude whether or not heuristic evaluation is an effective and useful method in design and development of VRUIs.

Furthermore there are many heuristic sets available for heuristic evaluation, although few available for VRUIs (only two found in this review), and the validation of the heuristics seems to vary between heuristic sets. A patchwork approach as suggested in one study (Hvannberg, Halldorsdottir and Rudinsky, 2012) and supported by one of the industry participants in the interviews, might be the most reasonable approach if industry practitioners should utilize heuristic evaluations as part of their process .

5.6 Contributions of the study

The main contributions of this study includes an overview of available heuristic sets specifically for VR is available through the academic literature and that they might lack thorough validation. Additionally it also show that most industry practitioners are not familiar with heuristic evaluation and heuristics, indicating that this method might not be extensively utilized in the VR industry.

The presented insights about the VR industry design process and methods utilized by the industry might be of interest to researcher studying related topics. This study also present an indication of whether heuristic evaluation could be utilized in the process of designing and developing VR-applications. This might be useful for industry practitioners or interaction designers looking to test such a method in their own design process working with VR-applications.

5.7 Further work

This study have presented an overview of available heuristic sets for VRUIs which have been shown to be a limited selection, there is also some evidence that they might lack thorough validation in terms of their effectiveness. Additionally, the heuristic sets that are the most applicable are not specifically directed towards the HMD-based VRUIs such as the industry practitioners in this study are concerned with. Although M-2017 focus on HMD-based VR, they to a large extent focus on hardware aspects, as well as software aspect and does not go into great detail on UI-specific aspects. S-2014 goes into more detail, but was initially not developed for HMD-based VR either. This indicates that more research on the field of usability heuristic for VRUIs, especially validating their effectiveness and maybe also developing new heuristics, or improving existing ones to better suit the work with VR-applications for HMDs might be a useful contribution.

Many areas of VRUIs, in particular in the typical form which we find it today in the form of HMD-based VR, are still mostly unexplored as much previous work are on different types of VR such as CAVE, workbench systems and similar. This includes work on best practices and guidelines, how users perceive the experience and what methods should be implemented in order to ensure a good user experience. Further work on how and if the results from previous research efforts can be transferred to the type of VR we see most of today can prove useful for today’s VR industry practitioners.

Another potential interesting area of research could be the designer’s role in the design and development of VR-applications. Most of the participants in this study mention UX/UI-designers, however the researcher seemed to be unable to locate such designer for participation in the study. One participant also described how they used designers occasionally, but with varying success. Further research on what impact incorporating designers from the beginning to the end in such projects would have on the final results, might be interesting and useful for both designers wishing to work with VRUIs as well as the leader in the VR industry concerned with how to put together appropriate teams for their projects.

Further, some participants brought up that what designers know today might not be enough when working with VR-applications, and brought up that skills and knowledge from other fields might be useful in this context. Research investigating how interaction designers can utilize the skills and knowledge of other areas of expertise, such as architecture and other areas who have extensive experience with designing 3D spaces, might prove useful both for interaction designers and educational institutions educating such designers.

References

Alonso-Ríos, D., Mosqueira-Rey, E. and Moret-Bonillo, V. (2018) A Systematic and Generalizable Approach to the Heuristic Evaluation of User Interfaces AU - Alonso-Ríos, David, *International Journal of Human–Computer Interaction*, 34(12), pp. 1169-1182. doi: 10.1080/10447318.2018.1424101.

Altarteer, S. *et al.* (2017) Development and heuristic evaluation of semi-immersive hand-gestural virtual reality interface for luxury brands online stores, i De Paolis, L. T., *et al.* (ed.) (vol. 10325 LNCS, pp. 464-477): Springer Verlag. doi: 10.1007/978-3-319-60928-7_39.

Anganes, A. *et al.* (2016) The Heuristic Quality Scale, *Interacting with Computers*, 28(5), pp. 584-597. doi: 10.1093/iwc/iwv031.

Association, U. P. (2009) *UPA 2009 salary survey*. Bloomingale IL. Available at: https://uxpa.org/sites/default/files/2009_UXPA_Salary_Survey_FULL.pdf (Accessed: May 30th, 2019).

Baxter, K. and Courage, C. (2005) *Understanding Your Users*. San Francisco, CA: Elsevier.

Benyon, D. (2014) *Designing Interactive Systems: A comprehensive guide to HCI, UX and interaction design*. Third edn. Harlow: Pearson.

Blom, K. J. and Beckhaus, S. (2014) The design space of dynamic interactive virtual environments, *Virtual Reality*, 18(2), pp. 101-116. doi: 10.1007/s10055-013-0232-y.

Bowman, D. A. *et al.* (2017) *3D User Interfaces*. Second Edition edn. Pearson Education, Inc.

Brinkmann, S. and Kvale, S. (2015) *Interviews: learning the craft of qualitative research in interviewing*. Thousand Oaks, Calif: Sage.

Bryman, A. (2016) *Social Research Methods*. 5th edn. Oxford: Oxford University Press.

Carter, L. and Potter, L. E. (2016) Designing games for presence in consumer virtual reality. Association for Computing Machinery, Inc, pp. 141-148.

Chuan, N. K., Sivaji, A. and Ahmad, W. F. W. (2015) Usability heuristics for heuristic evaluation of gestural interaction in HCI, i Marcus, A. (ed.) (vol. 9186, pp. 138-148): Springer Verlag. doi: 10.1007/978-3-319-20886-2_14.

Cummings, J. J. and Bailenson, J. N. (2016) How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence, *Media Psychology*, 19(2), pp. 272-309. doi: 10.1080/15213269.2015.1015740.

Desurvire, H. and Kreminski, M. (2018) Are Game Design and User Research Guidelines Specific to Virtual Reality Effective in Creating a More Optimal Player Experience? Yes, VR PLAY, *Cham*. Springer International Publishing, pp. 40-59.

Du, J. *et al.* (2018) CoVR: Cloud-Based Multiuser Virtual Reality Headset System for Project Communication of Remote Users, *Journal of Construction Engineering and Management*, 144(2), pp. 04017109. doi: doi:10.1061/(ASCE)CO.1943-7862.0001426.

Gault, B. and Sutcliffe, A. (2004) Heuristic evaluation of virtual reality applications, *Interacting with Computers*, 16(4), pp. 831-849. doi: 10.1016/j.intcom.2004.05.001.

Gonzalez-Holland, E. *et al.* (2017) Examination of the Use of Nielsen's 10 Usability Heuristics & Outlooks for the Future, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 61(1), pp. 1472-1475. doi: 10.1177/1541931213601853.

Gould, J. D. and Lewis, C. (1985) Designing for usability: key principles and what designers think, *Commun. ACM*, 28(3), pp. 300-311. doi: 10.1145/3166.3170.

Harrington, M. C. R. (2006) Situational learning in real and virtual space: Lessons learned and future directions.
Heydarian, A. *et al.* (2015) Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations, *Automation in Construction*, 54, pp. 116-126. doi: https://doi.org/10.1016/j.autcon.2015.03.020.
Hix, D. *et al.* (1999) User-centered design and evaluation of a real-time battlefield visualization virtual environment, pp. 96-103. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0032639423&partnerID=40&md5=a5beac6bac43bdcc22b2050e74d1f360.
Hix, D. *et al.* (1999) User-centered design and evaluation of a real-time battlefield visualization virtual environment, in Rosenblum, L.*, et al.* (ed.) *Ieee Virtual Reality - Proceedings.* pp. 96-103.
Hvannberg, E. T., Law, E. L.-C. and Lérusdóttir, M. K. (2006) Heuristic evaluation: Comparing ways of finding and reporting usability problems, *Interacting with Computers*, 19(2), pp. 225-240. doi: 10.1016/j.intcom.2006.10.001.
Hvannberg, E. T., Halldorsdottir, G. and Rudinsky, J. (2012) Exploitation of heuristics for virtual environments. pp. 308-317.
IDEO.org (2015) *The Field Guide to Human-Centered Design*. 1st edn.
Jerald, J. (2016) *The VR book: human-centered design for virtual reality*. First edition edn. Association for Computing Machinery.
Johnson, J. (2013) *Designing with the Mind in Mind : Simple Guide to Understanding User Interface Design Guidelines*. San Francisco, UNITED STATES: Elsevier Science & Technology.
Joyce, G. and Lilley, M. (2014) Towards the Development of Usability Heuristics for Native Smartphone Mobile Applications, in Marcus, A. (ed.) *Design, User Experience, and Usability. Theories, Methods, and Tools for Designing the User Experience*, *Cham*, *2014//*. Springer International Publishing, pp. 465-474.
Kalawsky, R. S. (1999) VRUSE—a computerised diagnostic tool: for usability evaluation of virtual/synthetic environment systems, *Applied Ergonomics*, 30(1), pp. 11-25. doi: https://doi.org/10.1016/S0003-6870(98)00047-7.
Kaur, A. and Yammiyavar, P. G. (2017) A comparative study of 2D and 3D mobile keypad user interaction preferences in virtual reality graphic user interfaces, in Spencer, S. N. (ed.). Association for Computing Machinery.
Leedy, P. D. and Ormrod, J. E. (2014) *Practical Research: Planning and Design*. 10th edn. Harlow: Pearson.
Lomas, N. (2017) The VR cycle is dead. Available at: https://techcrunch.com/2017/08/26/this-vr-cycle-is-dead/?guccounter=1&guce_referrer_us=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_cs=wZasd9Wi09k1RPE5qhqNRA.
Mack, R. L. and Nielsen, J. (1994a) *Usability Inspection Methods*. New York: John Wiley.
Mack, R. L. and Nielsen, J. (1994b) Executive summary, in Mack, R. L. and Nielsen, J. (ed.) *Usability Inspection Methods.* New York: John Wiley.
Mankoff, J. *et al.* (2003) *Heuristic evaluation of ambient displays*. Unpublished paper presented at Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Ft. Lauderdale, Florida, USA.
Merriam-Webster (2018a) *Usable*. Available at: https://www.merriam-webster.com/dictionary/usable (Accessed: 14 December 2018).
Merriam-Webster (2018b) *Usability*. Available at: https://www.merriam-webster.com/dictionary/usability (Accessed: 14 December 2018).
Molich, R. and Nielsen, J. (1990a) Improving a human-computer dialogue, *Commun. ACM*, 33(3), pp. 338-348. doi: 10.1145/77481.77486.
Molich, R. and Nielsen, J. (1990b) *Heuristic evaluation of user interfaces*. Unpublished paper presented at Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Seattle, Washington, USA.

Murtza, R., Monroe, S. and Youmans, R. J. (2017) Heuristic Evaluation for Virtual Reality Systems, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 61(1), pp. 2067-2071. doi: 10.1177/1541931213602000.
Nielsen, J. (1994a) *Enhancing the explanatory power of usability heuristics*. Unpublished paper presented at Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Boston, Massachusetts, USA.
Nielsen, J. (1994b) Heuristic Evaluation, in Mack, R. L. and Nielsen, J. (ed.) *Usability Insepection Methhos.* US: John Wiley & Sons, Inc.
Nielsen, J. (2012) *Usability 101: Introduction to USability*. Available at: https://www.nngroup.com/articles/usability-101-introduction-to-usability/ (Accessed: 12 December 2018).
Oliveira, E., Simoes, F. P. M. and Correia, W. F. (2017) Heuristics Evaluation and Improvements for Low-Cost Virtual Reality, in Nunes, F. L. S. and DeOliveira, J. C. (ed.) *2017 19th Symposium on Virtual and Augmented Reality.* pp. 178-187.
Paes, D. and Irizarry, J. (2018) A usability study of an immersive virtual reality platform for building design review: Considerations on human factors and user interface, in Wang, C.*, et al.* (ed.). American Society of Civil Engineers (ASCE), pp. 419-428.
Preece, J., Rogers, Y. and Sharp, H. (2015) *Interaction Design: Beyond human-computer interaction*. 4 edn. West Susexx: John Wiley & Sons Ltd.
Quinones, D., Rusu, C. and Rusu, V. (2018) A methodology to develop usability/user experience heuristics, *Computer Standards & Interfaces*, 59, pp. 109-129. doi: 10.1016/j.csi.2018.03.002.
Rusu, C. *et al.* (2011) *Usability Heuristics for Virtual Worlds*.
Shneiderman, B. and Plaisant, C. (2010) *Designing the user interface: strategies for effective human-computer interaction*. 5th edn. Boston, Mass: Addison-Wesley.
Suh, A. and Prophet, J. (2018) The state of immersive technology research: A literature analysis, *Computers in Human Behavior*, 86, pp. 77-90. doi: https://doi.org/10.1016/j.chb.2018.04.019.
Sutcliffe, A. G. and Kaur, K. D. (2000) Evaluating the usability of virtual reality user interfaces, *Behaviour and Information Technology*, 19(6), pp. 415-426. doi: 10.1080/014492900750052679.
Sutcliffe, A. G. *et al.* (2018) Reflecting on the Design Process for Virtual Reality Applications, *International Journal of Human–Computer Interaction*, pp. 1-12. doi: 10.1080/10447318.2018.1443898.
Sutherland, I. E. (1968) *A head-mounted three dimensional display*. Unpublished paper presented at Proceedings of the December 9-11, 1968, fall joint computer conference, part I. San Francisco, California.
Takatalo, J., Nyman, G. and Laaksonen, L. (2008) Components of human experience in virtual environments, *Computers in Human Behavior*, 24(1), pp. 1-15. doi: https://doi.org/10.1016/j.chb.2006.11.003.
Tromp, J. G. *et al.* (2018) Usability evaluation of the interactive 3D virtual cultural heritage museum display: Fountain of the lions software application, *International Journal of Engineering and Technology(UAE)*, 7(2), pp. 95-99. doi: 10.14419/ijet.v7i2.28.12887.

Appendix

Appendix 1 Pre-interview questionnaire
Appendix 2 Interview guide
Appendix 3 Follow-up questionnaire, heuristic evaluation
Appendix 4 Information letter and consent form

Appendix 1: Pre-interview questionnaire

Forberedende spørreskjema i forkant av intervju

Jeg vil gjerne be deg om å svare på noen forberedende spørsmål i forkant av intervjuet for å få litt bakgrunnsinformasjon fra deg. Denne bakgrunnsinformasjonen, gjør det enklere å kutte ut eventuelle spørsmål og punkter som ikke er relevante i intervjuet.

Takk for at du tar deg tid til å svare på spørsmålene, og tusen takk for at du tar deg tid til intervjuet og studien!

1. Jobber du (eller har du jobbet) med design og utvikling av Virtual Reality-applikasjoner og VR-brukergrensesnitt?
    a. Ja
    b. Nei

UTDANNING, BAKGRUNN OG ARBEIDSSITUASJON

2. Hva er din høyeste bestått utdanning?
    a. Ingen formell utdanning
    b. Videregående skole
    c. Fagbrev
    d. 1–2 års høyere utdanning
    e. Bachelorgrad
    f. Mastergrad
    g. Doktorgrad
    h. Annet; vennligst spesifiser:

3. Hva var din studieretning?

4. Hva er din nåværende stilling?

5. Hvor lang erfaring har du med design og utvikling av Virtual Reality-applikasjoner?
    a. Mindre enn 6 måneder
    b. 6 månedere–1 år
    c. 1–2 år
    d. 3–5 år
    e. Mer enn 5 år

6. Har du erfaring med design og utvikling for 2D-flater (nettsider, applikasjoner for mobil og nettbrett, software for desktop/laptop osv.)?
    a. Ja
    b. Litt
    c. Nei

KJENNSKAP TIL HEURISTIKK OG HEURISTISK EVALUERING

7. Er du kjent med heuristikk og heuristisk evaluering?

a. Ja
b. Litt kjent
c. Nei

(Hvis du ikke er kjent med heuristikk, kan du hoppe over siste del av skjemaet)

BRUK AV HEURISTIKK I 2D-BRUKERGRENSESNITT OG VR-BRUKERGRENSESNITT

8. Har du brukt heuristikk i design eller evaluering av 2D-brukergrensesnitt?
    a. Ja
    b. Nei
    c. Annet; vennligst spesifiser

9. Har du brukt heuristikk i design og evaluering av VR-brukergrensesnitt?
    a. Ja
    b. Nei
    c. Annet; vennligst spesifiser

Appendix 2: Interview guide

Intervjuguide

- *Jeg ønsker, hvis du samtykker til det, å gjøre lydopptak av dette intervjuet. Lydopptaket vil kun bli brukt av meg, for å renskrive svarene fra intervjuet slik at jeg ikke mister informasjon. Opptaket vil bli slettet etter at jeg har renskrevet alle svarene.*

- *Hvis det er noe du ønsker å si under intervjuet, som du ønsker ikke vil være med i opptaket, si gjerne ifra til meg så stryker stopper jeg opptaket.*

DEL 1: OPPFØLGING FRA FORBEREDENDE SPØRRESKJEMA OG INNLEDNING

Om erfaring med VR UID og arbeidsmetodikk

1. Kan du beskrive hvordan du jobber med VR-applikasjoner (in-house, konsulentbasert etc..)

2. Kan du fortelle meg om de to siste prosjektene du jobbet med (eller produktet du utvikler)?
    a. Hva slags applikasjoner var/er det?
    b. Hva gjør applikasjonene (hva gjør de, hva kan brukerne gjøre med de osv.)?
    c. Kan du beskrive prosessen med hvordan du og teamet ditt jobbet med disse to prosjektene? Hvilke metoder og verktøy brukte du/dere?
    d. Vil du si at dette er en typisk arbeidsflyt / metodikk for teamet ditt når du arbeider med VR-applikasjoner? Hvis ikke, kan du beskrive en typisk arbeidsflyt / metode?

3. Har du eller ditt team utviklet nye og unike metoder eller verktøy som du brukes når du jobber med VR-UIer, spesielt tilpasset deres arbeidsflyt og prosjekter?

4. Bruk teamet ditt andre metoder når du jobber med VR-brukergrensesnitt, sammenlignet med andre tradisjonelle (flate/2D) brukergrensesnitt? Hvis dere gjør det, kan du beskrive forskjellen?

Om definisjon på brukergrensesnitt

5. Hvis du skal definere brukergrensesnitt i VR, hva innbefatter et brukergrensesnitt?
    a. Når du tenker på de to siste prosjektene/applikasjonene du jobbet med, hvordan ville du beskrive brukergrensesnittet i disse applikasjonene, alt fra enkelt til komplekst?

HVIS deltager er kjent med heuristikk og heuristisk evaluering (hvis ikke, hopp til del 3):
DEL 2: HEURISTIKK OG HEURISTISK EVALUERING

(HVIS deltager har brukt heuristikk i design eller evaluering av 2D-brukergrensesnitt):
Heuristikk og HE for 2D-brukergrensesnitt

6. Når du brukte heuristikk i design eller evaluering av 2D-brukergrensesnitt, hvordan brukte du det? (Heuristisk Evaluering, som retningslinjer/råd eller annet?)

7. Hvilken heuristikk brukte du?

8. Hvordan valgte du hvilken heuristikk?

(HVIS deltager har brukt heuristikk i design eller evaluering av VR-brukergrensesnitt)
Heuristics og Heuristisk Evaluering for VR

9. Når du brukte heuristikk i design eller evaluering av VR-brukergrensesnitt, hvordan brukte du det? (Heuristisk Evaluering, som retningslinjer/råd eller annet?)

10. Hvilken heuristikk brukte du?

11. Hvordan valgte du hvilken heuristikk?

(HVIS heuristikk-settet som ble brukt opprinnelig er ment for 2D-brukergrensesnitt)
2D-heuristikk i design og evaluering av VR-brukergrensesnitt

12. Hvor effektivt mener du disse heuristikkene er når du designer og evaluerer VR-brukergrensesnitt?

Generelt om heuristikk og heuristisk evaluering som metode

13. Hva ser du som fordelene (hvis noen) ved å bruke heuristikk i design og evaluering av applikasjoner og brukergrensesnitt generelt?
    a. Hva ser du som fordelene (hvis noen) ved å bruke heuristikk i design og evaluering av VR-applikasjoner og VR-brukergrensesnitt?

14. Hva ser du som ulempene (hvis noen) ved bruk av heuristikk i design og evaluering av applikasjoner og brukergrensesnitt?
    a. Hva ser du som ulempene (hvis noen) ved å bruke heuristikk i design og evaluering av VR-applikasjoner og VR-brukergrensesnitt?

DEL 3: OM VR-BRUKERGRENSESNITT OG METODER/VERKTØY

Om designmetoder og verktøy for design og evaluering av VR-brukergrensesnitt

15. Er du kjent med noen form for designprinsipper, designråd eller retningslinjer for design av VR-brukergrensesnitt? Bruker dere noe slikt når dere jobber med deres prosjekter?
    a. Er du kjent med slike prinsipper, råd, retningslinjer når for tradisjonelle 2D-brukergrensesnitt?

16. Hvordan synes du de eksisterende designmetodene og verktøyene, som i utgangspunktet ble utviklet for tradisjonelle 2D-brukergrensesnitt, fungerer når man skal designe VR-brukergrensesnitt?

17. I hvilken grad ser du et behov for utvikling av nye designmetoder og verktøy (eller videreutvikling av eksisterende designmetoder og verktøy) for å gjøre prosessen med design og evaluering VR-brukergrensesnitt bedre og for å lage bedre og mer brukervennlige brukergrensesnitt?

Generelle tanker om VR-brukergrensesnitt

18. Hva anser du som de største forskjellene mellom å designe for tradisjonelle 2D-brukergrensesnitt sammenlignet med å designe VR-brukergrensesnitt?

19. Når det gjelder brukervennlighet, hva ser du på som de største utfordringene når man designer VR-brukergrensesnitt?

20. Har du noe annet du vil legge til?

21. Har du noen spørsmål om studien eller intervjuet?

Takk for at du tok deg tid til dette intervjuet!

Appendix 3: Follow-up questionnaire, heuristic evaluation

Påstander – evaluering av metode og heuristikker

Likert-scale
a: Agree, b: Somewhat agree, c: Neutral, d: Somewhat disagree, e: Disagree

Holdning til heuristisk evaluering

1. Evalueringen bidro til økt innsikt om mulige bruksproblemer med brukergrensesnittet, som bør eller kan utbedres i fremtiden

2. Evalueringen var enkel å gjennomføre

3. Jeg kan se for meg at en slik evaluering kan benyttes i vår utviklingsprosess

Holdning til heuristikkene brukt i evalueringen

1. Heuristikkene/retningslinjene var enkle å forstå

2. Heuristikkene/retningslinjene var relevante for brukergrensesnittet

3. Heuristikkene/retningslinjene var nyttige for å forstår utfordringene som ble funnet bedre

Appendix 4: Information letter and consent form

Forespørsel om deltakelse i studien:
"Usability Heuristics in Virtual Reality Interface Design"

Med dette skrivet spør jeg deg om du ønsker å delta i en studie, hvor formålet er å se på hvor godt eksisterende metodikk for design av tradisjonelle 2D-brukergrensesnitt fungerer når man skal designe brukergrensesnitt for VR. I dette skrivet finner du informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Bakgrunn og formål
I min avsluttende masteroppgave ved studiet i Interaksjonsdesign ved NTNU Gjøvik, gjennomfører jeg et studie hvor formålet er sammenligne hvor effektiv metodikk, spesifikt heuristikk, utviklet for VR-brukergrensesnitt er i design og evaluering av disse brukergrensesnittene, sammenlignet med generell metodikk utviklet for mer tradisjonelle brukergrensesnitt. I den forbindelse gjennomfører jeg intervjuer med profesjonelle aktører som arbeider, eller har arbeidet med, design av brukergrensesnitt for VR applikasjoner. Formålet er å se om det er samsvar mellom den metodikken som utviklet av det akademiske miljøet, og hva slags metodikk utøverne i bransjen bruker i sitt arbeid.

Ansvarlig institusjon for forskningsprosjektet: NTNU Gjøvik.

Hvorfor får du spørsmål om å delta?
Du har fått spørsmål om å delta i denne studien ettersom du arbeider, eller har arbeidet, med design og utvikling av VR-applikasjoner.

Hva innebærer det for deg å delta?
Deltagelsen i denne studien innebærer:
Et personlig intervju med hvor jeg vil stille deg spørsmål om din erfaring med design og utvikling av VR-brukergrensesnitt. Intervjuet gjennomføres ansikt til ansikt eller over Skype/telefon. Intervjuet er semistrukturert, hvor det åpnes for innspill fra deg utover de stilte spørsmålene i slutten av intervjuet. Intervjuet antas å ville ta mellom 30–60 minutter. Under intervjuet vil det bli gjort lydopptak og tatt notater. Notatene vil bli renskrevet og lagret elektronisk. Lydopptak vil bli slettet etter transkribering.
I forkant av intervjuet vil du bli bedt om å fylle ut et forberedende spørreskjema. Dette antas å ta ca. 5–10 minutter. Spørreskjemaet vil bli fylt ut på papir eller via spørreskjema gjennom tjenesten Survey Monkey (www.surveymonkey.com)

Hvis aktuelt, kan du også bli spurt om:
Å delta i et oppfølgende eksperiment, workshop eller intervju avhengig av resultatene fra den første intervjurunden.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle opplysninger om deg vil da bli anonymisert. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

Det er kun jeg, **Katrine Øvstegård** og min veileder ved NTNU Gjøvik, **Mariusz Nowostawski** som vil ha tilgang til dine personopplysninger.

Navnet og kontaktopplysningene dine vil jeg erstatte med en kode som lagres på egen navneliste adskilt fra øvrige data.

Jeg ønsker, hvis du samtykker til dette, å takke deg for innsatsen i studien med fullt navn, under kapittelet «*Acknowledgements*» i den endelige oppgaven.

Hva skjer med opplysningene dine når prosjektet avsluttes?
Prosjektet skal etter planen avsluttes 1. juli 2019. Personopplysninger og kodenøkkel vil slettes ved prosjektslutt.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:
innsyn i hvilke personopplysninger som er registrert om deg,

- å få rettet personopplysninger om deg,
- få slettet personopplysninger om deg,
- få utlevert en kopi av dine personopplysninger (dataportabilitet), og
- å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra **NTNU Gjøvik** har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Ta gjerne kontakt med meg, **Katrine Øvstegård** på **katrinov@stud.ntnu.no,**
eller min veileder ved NTNU Gjøvik, førsteamanuensis **Mariusz Nowostawski** på **mariusz.nowostawski@ntnu.no** om du har spørsmål om studien eller ønsker å benytte deg av dine rettigheter.
NSD – Norsk senter for forskningsdata AS: på epost (personverntjenester@nsd.no) eller telefon: 55 58 21 17.

Med vennlig hilsen

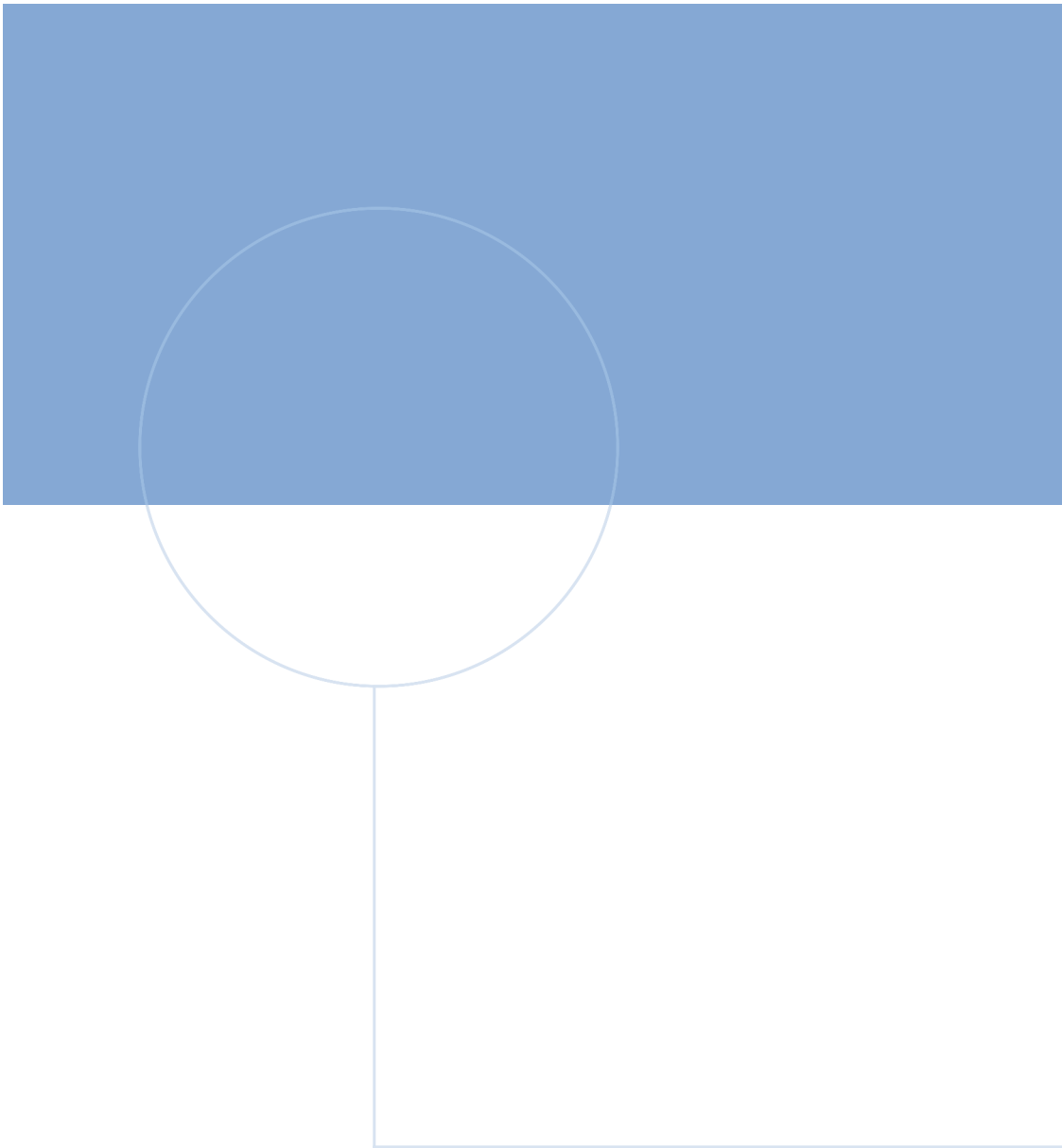
Masterstudent, **Katrine Øvstegård** Veileder, **Mariusz Nowostawski**

Samtykkeerklæring
Jeg har mottatt og forstått informasjon om prosjektet «Usability Heuristics in Virtual Reality User Interface Design», og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å delta i intervju
- ☐ at jeg kan kontaktes for oppfølgende aktivitet etter intervjuet (eksperiment, workshop eller intervju), hvis dette blir aktuelt
- ☐ at jeg takkes for min innsats i studien med fullt navn under «Acknowledgements» i den endelige prosjektrapporten

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet, ca. juli 2019

(Signert av prosjektdeltaker, dato)



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