MASTER'S THESIS 2020

An Asymmetric Virtual Reality Tool for Town Development

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LTH | LUND UNIVERSITY

EXAMENSARBETE
Designvetenskap

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December 16, 2020

Master's thesis work carried out at
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Abstract

Residents living in small towns that are a part of a bigger municipality may sometimes feel overlooked as they sense that they have lesser influence. Smaller towns may not have the resources or consider the need for integrating technology with the town, thus possibly making it harder for the residents to stay updated and be in contact with the town. By focusing on the residents' needs, a digitalised platform with desired features was developed. The digitalised platform was, besides serving as a tool to increase the sense of influence among the residents, extended with virtual reality to explore the usefulness of an asymmetric collaborative environment in a town development tool. Ultimately, the platform consisted of a touchscreen with virtual reality integrated into the platform.

The structure and the development of the thesis was a result of a user-centred design process. The project was divided into 3 major phases, starting with the conceptual phase to identify the users' needs. Then, the prototyping phase, where the users' needs were transformed into Lo-fi prototypes, and ultimately a Hi-fi prototype. Lastly, the Hi-fi prototype was tested by users in the evaluating phase to identify usability errors and to gather user data as regards to the purpose and goal of the thesis.

The purpose of the thesis was to identify if asymmetric collaborative interactions between VR and a touchscreen could be used as a tool for professional use, and the usefulness of such a system. The data obtained from the research showed that asymmetric collaboration between VR and a touch screen is only a moderately useful concept, as the usability was not obvious in a city planning platform. However, the concept was well-received by the users. Given a platform that is developed solely for an asymmetric collaborative environment, the potential would increase tremendously.

Keywords: Virtual Reality, Asymmetric Collaboration, Collaborative Virtual Environment, User-centred Design, Town Planning

Sammanfattning

Invånare som bor i småstäder som ingår i en större kommun kan ibland känna sig förbisedda eftersom de känner att de har mindre inflytande. Mindre städer kanske inte har tillräckligt med resurser eller överväger behovet av att integrera teknik med staden, vilket möjligen gör det svårare för invånarna att hålla sig uppdaterade och vara i kontakt med staden. Genom att fokusera på invånarnas behov utvecklades en digitaliserad plattform med önskade funktioner. Den digitaliserade plattformen utvidgades, förutom att fungera som ett verktyg för att öka känslan av inflytande bland invånarna, med virtual reality för att utforska nyttan av en asymmetrisk samarbetsmiljö i ett stadsutvecklingsverktyg. I slutändan bestod plattformen av en pekskärm med virtuell verklighet integrerad i plattformen.

Avhandlingens struktur och utveckling var ett resultat av en användarcentrerad designprocess. Projektet delades in i tre stora faser, med en början på den konceptuella fasen för att identifiera användarnas behov. Därefter prototypfasen, där användarnas behov förvandlades till Lo-fi-prototyper, och i slutändan en Hi-fi-prototyp. Slutligen testades Hi-fi-prototypen av användare i utvärderingsfasen för att identifiera användbarhetsfel och för att samla in användardata vad gäller syftet och målet med avhandlingen.

Syftet med avhandlingen var att identifiera om asymmetriska samverkande interaktioner mellan VR och en pekskärm kunde användas som ett verktyg för professionellt bruk och användbarheten av ett sådant system. De erhållna uppgifterna från forskningen visade att asymmetriskt samarbete mellan VR och en pekskärm är ett endast måttligt användbart koncept, eftersom användbarheten inte var uppenbar i en stadsplaneringsplattform. Däremot mottogs konceptet väl av användarna. Potentialen skulle ökat enormt om plattformen enbart utvecklats med hänsyn för en asymmetrisk samarbetsmiljö.

Nyckelord: Virtual Reality, Asymmetriskt samarbete, Samverkande virtuell miljö, Användarcentrerad design, Stadsplanering

Acknowledgements

I would like to dedicate this section to give my thanks and express my gratitude to everyone that has been a part of my thesis in any way. My thanks to my family that has assisted me in every possible way, including having to drive me back and forth between Eslöv and Lund (sorry) because of the ongoing pandemic. An extra thanks to my supervisor Joakim Eriksson for his superb and professional guidance and support throughout the whole project and even before the project. An additional thanks to my examiner Mattias Wallergård for giving me opportunities and supporting me before the project. I would also like to thank Jan Malmgren from Veberöd for assisting me during the early stages of the project and helping me gather data from the residents of Veberöd. Furthermore, I want to express my strong gratitude to Johan Pettersson for helping me from day one at LTH and for also proofreading my thesis.

My special and dedicated thanks to my dear girl Ruby Wan Lam Lo, who has been a part of my life and a good influence since the day we met, keeping my motivation high and growing together through the ups and downs. Thank you.

Lastly, thanks to Simon Holk for inspiring me to seek opportunities in the VR lab and exploring both VR and AR with me.

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Chapter 1
Introduction

1.1 Background

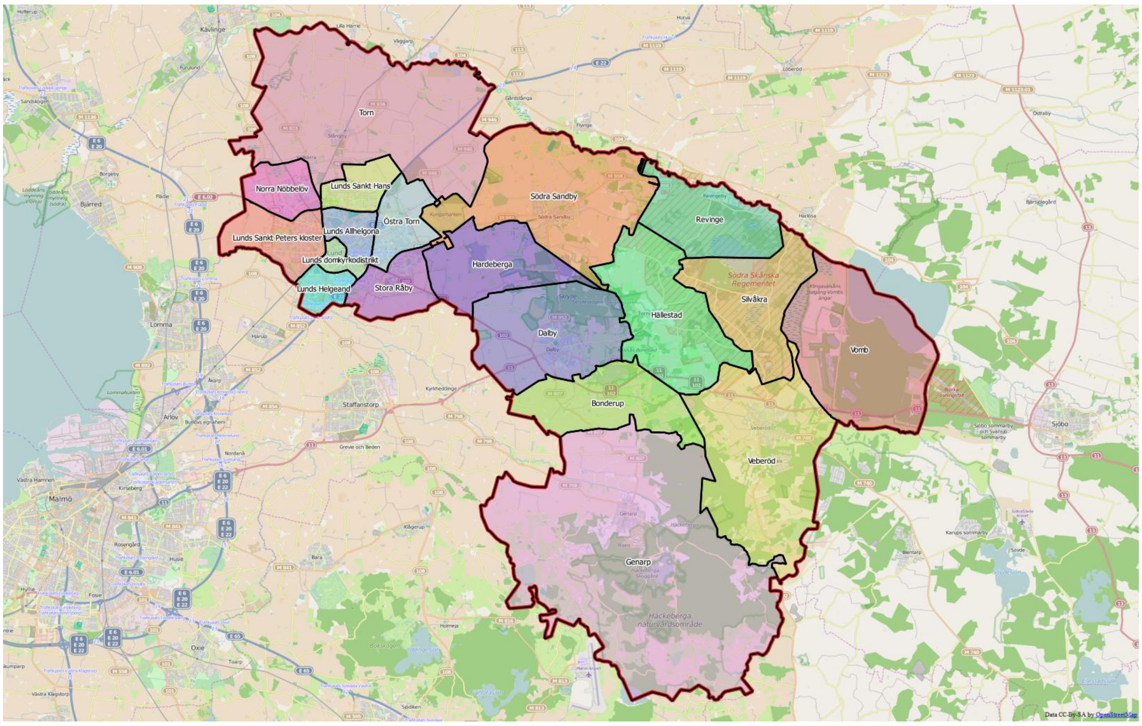


Figure 1.1: The district division in Lund municipality. Veberöd is highlighted in yellow, middle right. Lantmäteriet [1]

Veberöd is a locality among several in Lund municipality, see Figure 1.1. With a population of 5550 (2019), Veberöd makes up 4.4% of the population of Lund municipality (124935, 2019) [2]. Being a part of a bigger municipality, villagers may sometimes feel overlooked as they sense that they have lesser influence. Smaller towns may not have the resources or consider the need for integrating technology with the town, thus possibly making it harder for the residents to stay updated and be in contact with the town. However, Veberöd is one of many towns that sees the possibilities and usefulness of a smart town. A common definition of a smart town does not only include internet of things (IoT), self-driving cars, delivery by drones, but also how to effectively enhance the residents' lives [3]. Veberöd has presented a number of possible ideas that can be included in a smart town, such as a smarter way to issue fault reports, visualising of virtual buildings to provide better insight for town planning, visualising water consumption for analysis of behavioral patterns and energy efficiency, waste management and the list goes on. As a vision, Veberöd wishes to install a large touchscreen with smart features in, perhaps, the city hall, which would allow the residents to stay updated and also get in contact with the town through the platform.

My take on a smart town to increase the sense of influence among the residents, combined with the vision of Veberöd, is to develop a digitalised platform with relevant features to make the residents more engaged. The relevant features will be a result of the residents' needs. By focusing on the residents' needs, the features will most likely be appreciated. The digitalised platform will, besides serving as a tool to increase the sense of influence among the residents, be extended with virtual reality (VR) to explore the usefulness of an asymmetric collaborative environment in a town development tool. The meaning of an asymmetric collaboration environment – or interacting asymmetrically – in this thesis is that different users interact with different user interfaces on the same platform. Ultimately, the platform will consist of a touchscreen with virtual reality integrated into the platform.

1.2 Purpose and Goal

The thesis will focus on how to integrate virtual reality as a medium to plan and develop a smarter town. The purpose is to research and evaluate the ease of using asymmetric interactions in a collaborative virtual environment and how useful such an approach is using virtual reality and a touchscreen. The following questions were formulated:

- How useful is an asymmetric collaborative experience with virtual reality and a touchscreen as a tool for planning smart towns?
- How can such an approach be designed with usability in mind?
- How intuitive are interactions in a collaborative virtual environment with Virtual reality and a touchscreen?

1.3 Limitations and Scope

Throughout the development of the town development platform, feedback has been given by Veberöd. In that way, major functionalities have been a result of Veberöd's requests. To fulfill the thesis goal, the system was then extended with virtual reality, to create an asymmetric collaborative virtual environment. The test cases for the asymmetric experience were, however, limited to only virtual reality and a touchscreen, due to the augmented reality hardware not being available during the major part of the development of the system and a time limit of around 20 weeks for the thesis. Therefore, the decision was made to only include the interactions between virtual reality and a touchscreen in the final product. The thesis will still briefly address the possible usages of augmented reality.

Chapter 2
Theory & Technology

2.1 Design Methods

When designing and developing a product, it is crucial to follow design principles and design methods that have been researched and tested to ensure that the end result will be easy to use, useful, and likeable [4]. This will also prevent unnecessary errors during development, which instead could have led to the project taking more time, costing more, and in the worst case failing.

2.1.1 User-centred design

User-centred design (UCD), also called human-centred design (HCD), is a design approach which includes a set of different design methods to put the users in the center when designing and developing a product [5]. It is done by focusing on the users' needs, capabilities, and behavior, then designing to accommodate those. The UCD process is iterative, involving four distinct phases:

1. Specifying and understanding the context of use, by identifying the users, learning about the users' needs, and reviewing ideas with stakeholders if they are involved.

2. Specifying the user requirements by reviewing requirements of the product from stakeholders and identifying the user goals that should be met to succeed with the product.

3. Creating design solutions and developing. This phase is iterative and begins with prototyping rough concepts to a complete design.

4. Evaluating the product by constructing usability tests with, ideally, the identified users to gain valuable feedback of the product. Evaluating is crucial in product development.

There are many ways to achieve good UCD. The UCD variant, which consists of several design methods for each UCD phase, may be chosen according to the type of project and situation, e.g., the needs, requirements, timeline, and environment of the project.

2.1.2 Data collection

To understand the users' needs, collecting data early is crucial [6]. An easy, efficient, and cheap way to collect a large sample of quantitative data, i.e., yes/no or multiple choices questions, is to issue questionnaires. Qualitative data can also be collected by adding free-form text input fields, also known as open questions, whereas it is called closed questions for quantitative data.

2.1.3 Bodystorming

When generating interaction ideas or testing conceptual ideas, in which any kind of physical movement is required, bodystorming is a good technique to utilise [7]. It sets the researcher or the test user in a specific use case for the product, where the tester has to role play and act as if the product was being used. During this process, a researcher may observe the test user to gauge how intuitive the product use is. In addition, bodystorming is very useful when testing VR interactions because their main input methods are hand gestures and sometimes movements.

2.1.4 Prototyping

A prototype is an early version or manifestation of a design or product [4]. It gives the stakeholders or test users the possibility to interact with and try the design/product before it has been finished and released. In that way the researcher can observe the user and collect reasonable feedback about the product. Prototypes comes in different stages, where low fidelity (Lo-fi) prototypes, the earlier stage, are usually made of paper or other low cost materials. Creating a Lo-fi prototype is fast, easy, and cheap, but it does not allow user interactions. However, it gives the users an early visualisation of different design solutions, which can easily and quickly be improved as they mostly serves as a suggestion or idea. The later stage, Hi-fi prototypes, provides the users with close to a true representation of the finished product, including real and working interactions. The feedback and observations of a Hi-fi prototype grant truer human performance data of how the finished product would have been used by an actual user.

2.1.5 Usability testing

A good approach when evaluating a product, with the user in mind, is to conduct a user test. This is best done by constructing a user test plan, which serves as a blueprint that describes the different parts of the user test, as well as guiding the test moderator during the test [6]. Following a test plan ensures that the user tests will work towards the same goal and purposes, as the structure of the test is predetermined. The quantity of users in a user test does not have to be a large number; according to research by *Nielsen* and *Landauer*, 5-15 samples suffice to achieve good usability data in regards to the efficiency [8]. It is further explained that conducting several tests with fewer users could be more efficient than a single test with a large number of users [9].

2.2 Extended Reality

Extended reality (XR) is not a new medium, nor a new concept. It is an umbrella term that includes the entire spectrum of real and combined virtual environments to completely virtual computer-generated reality, e.g., augmented reality, mixed reality, and virtual reality [10]. It has been featured in various settings – in entertainment, for educational purposes, as assistive tools, and much more. The experience can be extended into a collaborative virtual environment (CVE), making it possible to share the experience and in addition, interact with multiple users in the same virtual environment [11]. With the rise of IoT solutions [12], planning a smart home can be done with ease. Towns are no exception when it comes to the possibilities of integrating IoT.

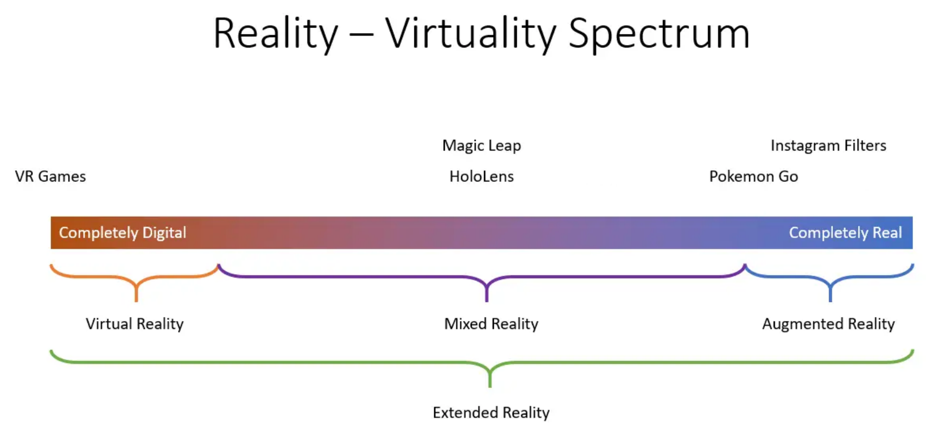


Figure 2.1: Reality - virtuality spectrum, ranging from completely digital to completely real. Examples of usage for the various technologies are shown above the spectrum (minor changes on the source figure have been made). Liu [13]

2.2.1 Virtual Reality

Virtual Reality (VR) is a computer technology by which the users are placed inside virtual computer-generated environments [14]. The users are able to interact with 3D objects and user interfaces while being immersed in a simulated 3D world. Common use cases for VR are entertainment and educational purposes [15]. A way to enable such an experience is by the use of a head-mounted display (HMD) [16]. The commonly used Head-mounted displays for VR, as of today, have two small displays, one for each of the wearer's eyes. This creates the illusion of depth, also known as stereoscopy [17], which enhances the user's immersive experience. The head-mounted displays come with the ability to register either 3 or 6 degrees of freedom

(3-DoF or 6-DoF), where 3-DoF describes tracking rotational movements with the head, and 6-DoF extends that with translational movement [18].

2.2.1.1 Oculus Quest

Oculus Quest is a standalone wireless head-mounted display created by Oculus VR, Facebook, illustrated in Figure 2.2. Standalone, in this case, implies being able to operate without having to rely on other hardware, e.g., a computer or a smart phone.

Figure 2.2: The Oculus Quest HMD and its two controllers. Simulation Lab Software [19]

However it comes with the drawback that it cannot perform well with graphically demanding applications. To circumvent the drawback, Oculus VR introduced Oculus Link, which is a software that enables the Oculus Quest to connect to a computer, utilising the computer's hardware to run the graphically demanding applications instead of directly on the HMD [20]. Oculus Quest also offers 6-DoF unlike its predecessor, Oculus Go, which only has 3-DoF. Oculus Quest comes with two 6-DoF controllers, but it also includes a new experimental input method: hand tracking. Hand tracking delivers a new sense of presence, more natural interactions, and enhances social engagement with fully tracked hands and fingers. The basic gestures with hand tracking in Oculus Quest are comparable with the gestures on the HoloLens, an augmented reality (AR) HMD, which uses hand tracking as its main input method [21][22].

2.2.2 Augmented Reality

Augmented Reality (AR) enhances and alters the user's physical world by blending computer-generated overlays, e.g., user interfaces, with the real physical world [23]. The users can interact with computer-generated user interfaces in real-time while having a clear view of the real world, whereas in VR the users are fully surrounded and immersed in a virtual world. The common input methods for AR are hand gestures, and voice commands.

Figure 2.3: A 3D model has been placed in the physical world

2.3 Unity

Unity is a game engine made by Unity Technologies. It can quickly run a project without having to compile and build beforehand, making it a good and effective prototyping tool. Unity supports cross platform, meaning a developer can port a project to multiple other platforms with ease, which makes it a good choice when developing applications for XR, which includes multiple platforms [24].

Chapter 3

Previous Work

3.1 Asymmetric interactions

Jerônimo, Henrique, and Anderson have studied and published a conference paper about asymmetric interactions in a collaborative virtual environment [25]. They conducted a user test of 36 participants to evaluate the performance and collaboration aspect between working symmetrically in AR and symmetrically in VR with working asymmetrically in VR and AR; see Figure 3.1. Their results indicated that working asymmetrically in VR and AR achieved significantly better performance than working symmetrically. Their study is relevant and serves as a good reference, as a purpose is to evaluate the asymmetric performance between a touchscreen user and a VR user.

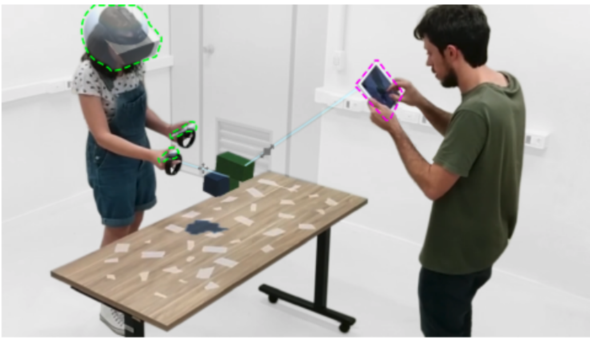


Figure 3.1: Two participants are interacting with a 3D object simultaneously, each with different user interface/technology. Grandi [25]

3.2 Virtual Collaborative Design Environment

Roupé, Johansson, Maftei, Lundstedt, and Viklund-Tallgren have published a paper about virtual collaborative design environment (ViCoDE) [26]. In their study, a multi-touch table was used together with VR systems in a collaborative environment with immediate feedback to evaluate the usability of collaborating in a CVE; see Figure 3.2. The use case was to design new healthcare environments. Their results showed that the collaboration between VR systems and a multi-touch table achieved a good outcome, as it fosters better participation, communication, understanding, knowledge sharing, and collaboration between different stakeholders.

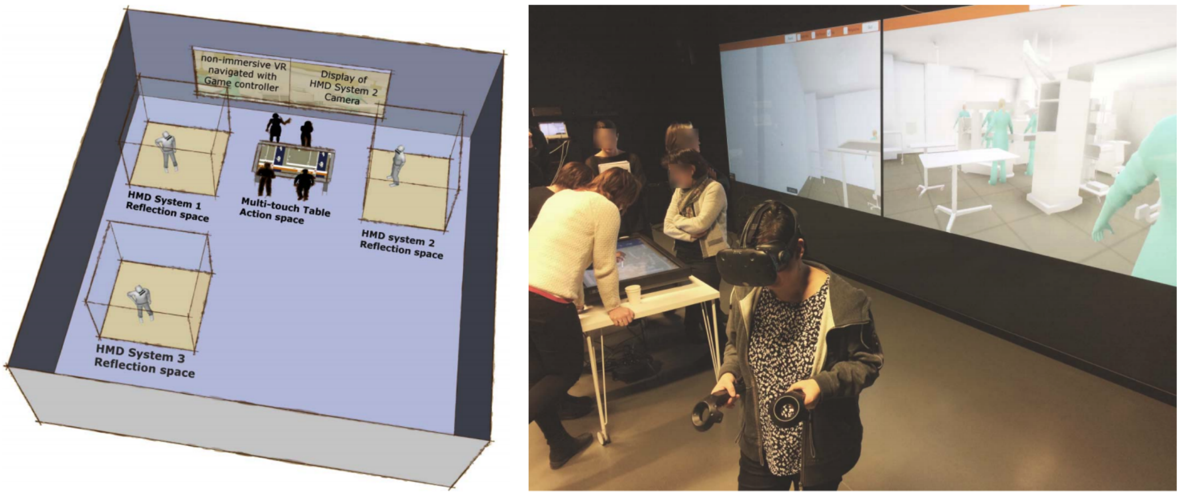


Figure 3.2: Overview of the asymmetric collaborative testing environment. Roupé [26]

This paper is very relevant and serves as a good reference, as it evaluates the collaboration between VR systems and a multi-touch table, but furthermore also brings up urban planning. However, as their user tests were mainly around designing new healthcare environments, the study about the asymmetric collaborative experience in city planning and the usability of such a system is left open for discovery.

3.3 Min stad

Min stad is a web-based city planning application replicating the city of Göteborg (Göteborgs Stad [27] (see Figure 3.3)). As a user you can place markers on the interactive map of the city. These markers act as different options a user can select depending on what information they want to mediate. The workflow and interaction methods used in the web-based application was taken into consideration when designing the user interface.

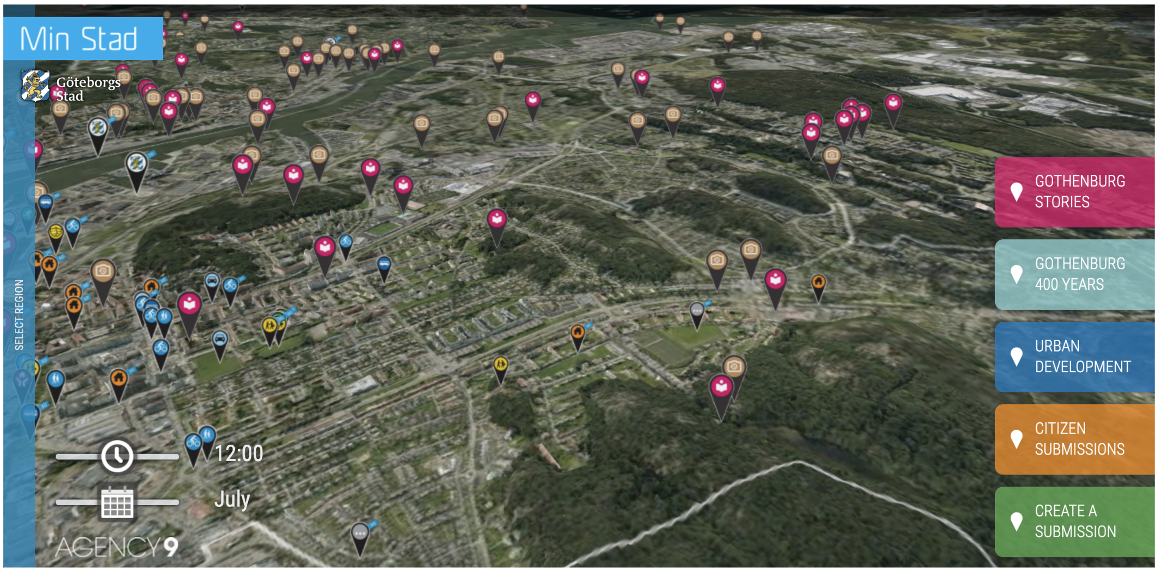


Figure 3.3: Min stad by Göteborgs Stad. Göteborgs Stad [27]

Chapter 4
The Design Process

4.1 Structure of the project

The project was divided into 3 major phases (see Figure 4.1), starting with the conceptual phase to identify the users' needs by specifying the context of use, as well as the user requirements. This is best done by collecting user data, e.g., by sending out questionnaires to the target group. The next phase is prototyping, where the users' needs are transformed into Lo-fi prototypes, and ultimately a Hi-fi prototype after iteratively having improved and adjusted the prototype. Lastly, the Hi-fi prototype is tested by the user group in the evaluating phase to identify usability errors and to gather user data as regards to the purpose and goal of the thesis.

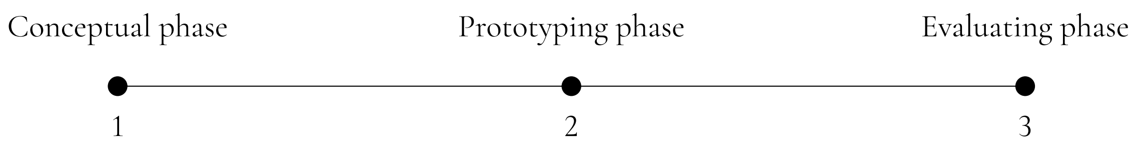


Figure 4.1: The different phases of the project in chronological order

Chapter 5
Conceptual Phase

5.1 Initial Project Meeting

The project was initiated with a meeting together with the project's supervisor and a stakeholder. The stakeholder shared his visions and ideas of a smart town, and also discussed the potential end-users. Numerous potential features were then presented by both the stakeholder and the supervisor. While only a few features would be included in the final product, every presented feature/idea would be looked at with the users in mind, to be able to select the best few features/ideas that felt most relevant for the project.

5.2 The Context of Use

To determine the context of use, the problem should be evaluated to identify the purposes of the features. The potential end-users should also be kept in mind during the process. The problem that was to be evaluated to identify the use cases could be divided into two parts: how to increase the sense of influence among the residents on a digitalised platform and the usefulness to collaborate asymmetric with virtual reality and a touchscreen. However, since it would not be efficient to cover all possible use cases, limitations had to be applied, and thus only a couple of possible fundamental use cases were included. In this stage the use cases were shaped through an end-user's perspective, mainly to get a conceptual idea. The use cases would further be shaped after receiving data from the surveys. The initial use cases are shown in Table 5.1.

Table 5.1: The table displays the initial use cases for both touchscreen and virtual reality.

Initial use cases		
Touchscreen		
Use Case	**Actor**	**Basic Flow**
Gaining information of the town.	Town resident.	The resident wants to know what activities are available and their opening times, but she is unsure how to start. She remembers that the city hall has a large touchscreen with information about the town. She walks to the city hall and starts using the touchscreen. She then filters the 3D map to only display information. After navigating around, she has gained enough information.
Adding information.	Shop owner.	The shop owner has recently opened a new shop. He wants the residents to know more about the shop. He remembers that the city hall has a large touchscreen with information about the town. He walks to the city hall and starts using the touchscreen. He then adds a marker where his shop is located and adds information about his shop.
Viewing reports.	Municipal employee.	The residents have issued fault reports on the touchscreen platform. The municipal employee filters the view to only display reports. He can then decide which problems have to be resolved.
Virtual reality		
Issuing a report.	Town resident	The resident wants to report a problem he found in the town, but he thinks that the touchscreen is not accurate enough. He, instead, uses virtual reality to see the digital town in real-world scale. He then places a marker exactly where he found the problem. **Alternative:** The touchscreen is occupied. The resident uses virtual reality simultaneously with the touchscreen user.

5.3 Specifying the Users

To get a better understanding of how the users feel about certain features, their view of a smart town, as well as what they would want to have in such a service, a questionnaire was constructed and sent to two different target groups. One was specifically sent to the end-users for this project, i.e., people that live in Veberöd municipality; the other was sent to people that live in a city. In this way, the sample size would most likely be large and would also enable comparison between people living in a village/town and people living in a city. The questionnaires included both quantitative and qualitative questions, giving the respondents the choice to also add their thoughts, rather than just selecting predetermined answers.

5.4 Survey

The questionnaire was constructed in Google Forms, a survey administration app. Despite the main target group being people that live in Veberöd municipality, it was of interest to also gather data from people globally, mostly living in cities. Therefore, the questionnaire was made in two versions, one for each group. The global version was sent through social media, which attracts people globally, and the Veberöd version was posted on the website of Veberöd as a blog post (Veberöd [28]). The purpose of the questionnaire was to gather both quantitative and qualitative data regarding smart town services, mainly focusing on fault reports, water consumption, and the possibility to give suggestions. In total the respondents had to answer 14 questions, were 12 were quantitative and 2 qualitative. The qualitative questions were non-mandatory, to ensure that the answers were not written just to proceed to the next section. The first 3 quantitative questions were for general data (i.e., gender, age, technical usage), which will only be mentioned briefly as they did not serve any genuine purpose, while the rest of the questions are discussed in more detail and presented as Figure 5.1 to Figure 5.9. To make the questionnaire less time-consuming, the various questions had a Likert scale [29] of a range from 1 to 5, where 1 represented *completely disagree* and 5, *fully agree*.

5.5 Results from the Survey

199 respondents completed the questionnaire: 111 (55.8%) from Veberöd municipality and 88 (44.1%) from the global variant. The distribution between female and male was very even: 95 (47.7%) women, 99 (49.7%) men, and 5 (2.5%) other.

5.5.1 Fault report

One of the possible key features for the service that had been brought up during the meetings with both the supervisor and the stakeholder was the ability to issue and view fault reports. To determine and get a sense of what the respondents think of the idea of issuing fault reports as a function, the first few questions were about fault reports. Question 1, Figure 5.1, was whether the respondent thought issuing fault reports was a good way to get involved in their city/town, in which the majority (57.7%) of the Veberöd respondents thought it was a good way, while the global responses were more spread out with 21.8% on score 5, 36.8% on 4, and 31% on 3. A reason why Veberöd and global differs could be that the sense of belonging is stronger in villages and hence the enthusiasm to issue fault reports. For question 2 and question 3, Figure 5.2 and Figure 5.3, we wanted to know if the usage of a 3D map to issue and view fault reports was a likeable approach among the respondents. Luckily both issuing and viewing on a 3D map scored high among both the Veberöd and the global respondents, with 69.5% and 66.7%, respectively, for Veberöd; and 43.7% and 50%, respectively, for the global respondents. Question 4, Figure 5.4, was a straightforward question if the respondents would issue a fault report given that they have seen a problem.

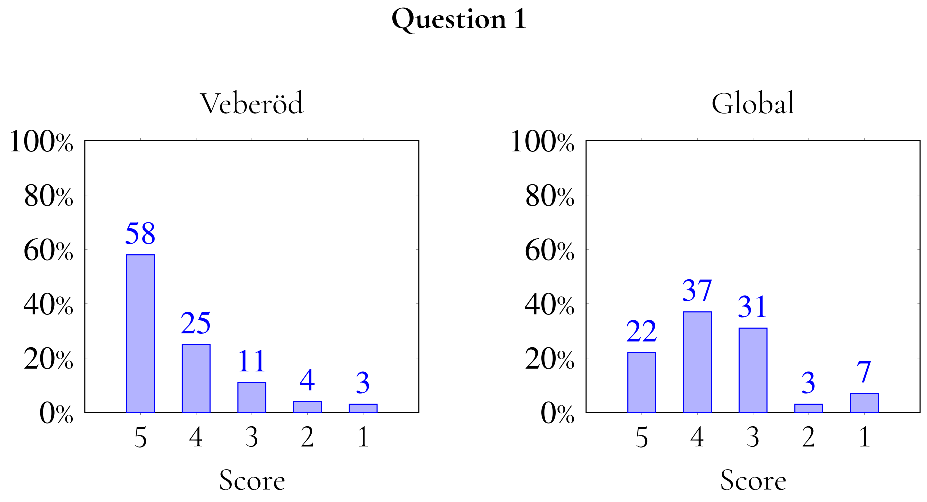


Figure 5.1: Issuing fault reports, e.g., reporting a broken road, is a good way to get involved in my city/town.

Comparing question 4 with question 1, the results for question 4 were expected, and they also strengthen the argument that villagers have a stronger sense of belonging. The Veberöd respondents had a majority (52.3%) of score 5, while the global respondents (same as question 1) were more spread out with a mean value of score 3.

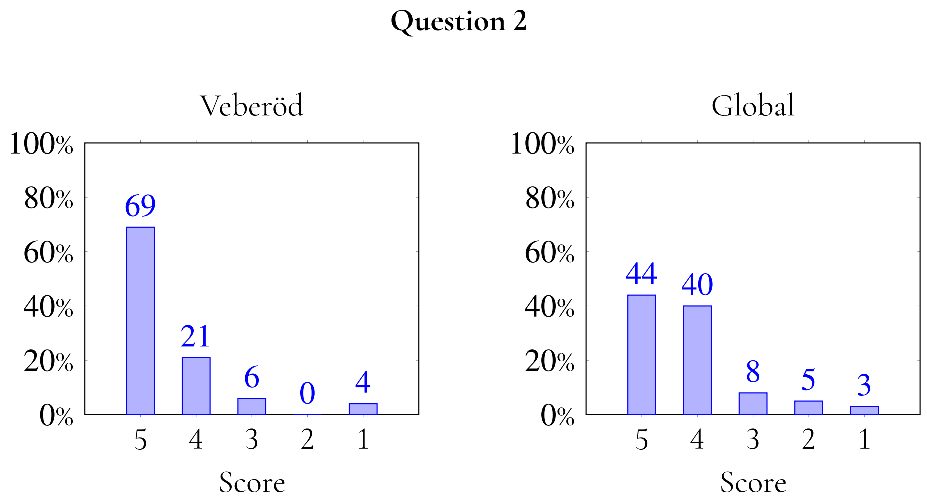


Figure 5.2: Using a 3D map to pinpoint the location of the problem is a good way to issue a fault report.

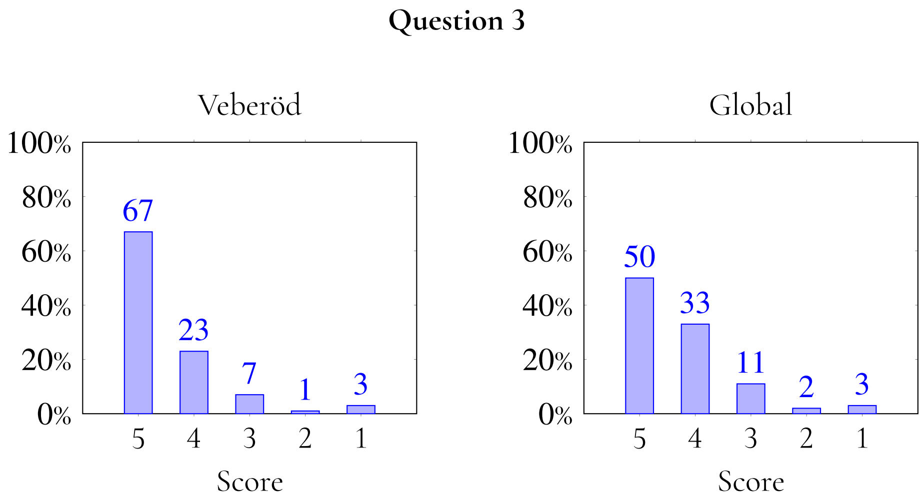


Figure 5.3: Being able to see all the active fault reports in my city/town on a 3D map is a good feature.

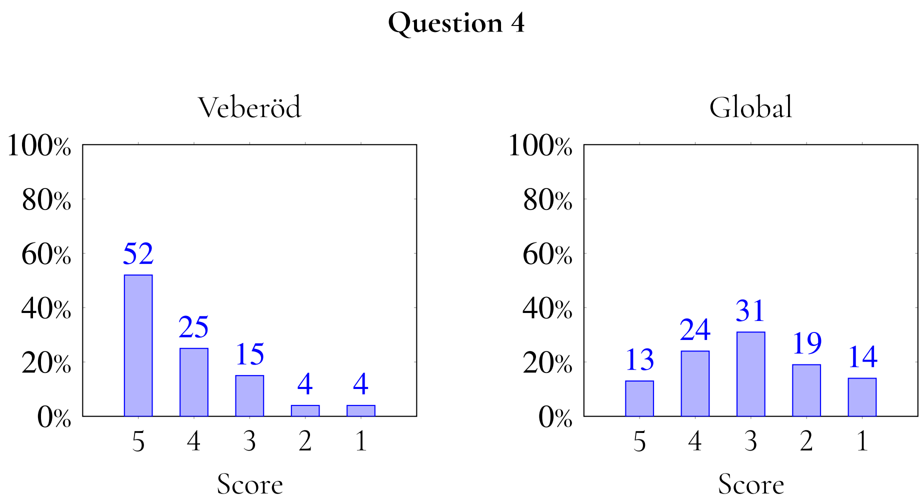


Figure 5.4: I would do a fault report if I see a problem in my town/city.

5.5.2 Water consumption

Another possible key feature that was brought up during the meetings was the ability to view neighbourhood-related information, focusing on the environment, such as a neighbourhood's water consumption. The idea was to enable viewing and comparing one's neighbourhood with another neighbourhoods and then possibly extend it into a kind of challenge to increase one's motivation to consume less. However, the respondents' interest in this topic was not as pronounced as the results of the fault reports, with only 28.2% on score 5 from the Veberöd respondents, and 36.4% on score 5 from the global respondents regarding question 5; see Figure 5.5.

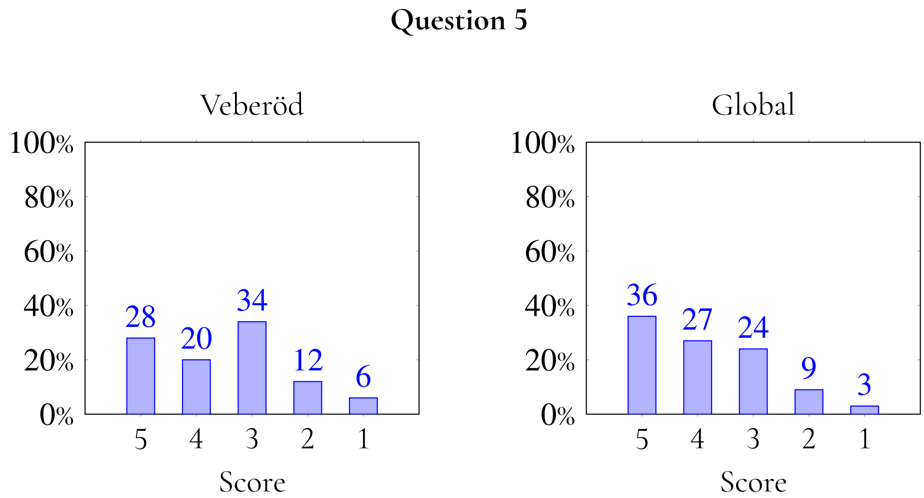


Figure 5.5: I would like to see information, such as the water consumption of my city/town.

The respondents' low interests did not change when asked about the idea of viewing the information on a 3D map on question 6 (see Figure 5.6), with 28.2% and 36.4%, respectively, on score 5 from the Veberöd and the global respondents. Conversely, when asked about how much the respondents care about the environment on question 7 (see Figure 5.7), it scored high from both the Veberöd and the global respondents: 73% and 46.6% on score 5, respectively. In addition, the global variant had 36.4% on score 4. While viewing neighbourhood information regarding the environment was not likeable or considered interesting, most likely because of privacy reasons and perhaps over concerns of having their environmental habits exposed publicly, the high score on the environmental topic (question 7, Figure 5.7) shows that the respondents would likely want to know ways to contribute to the environmental sustainability if a better way would be presented.

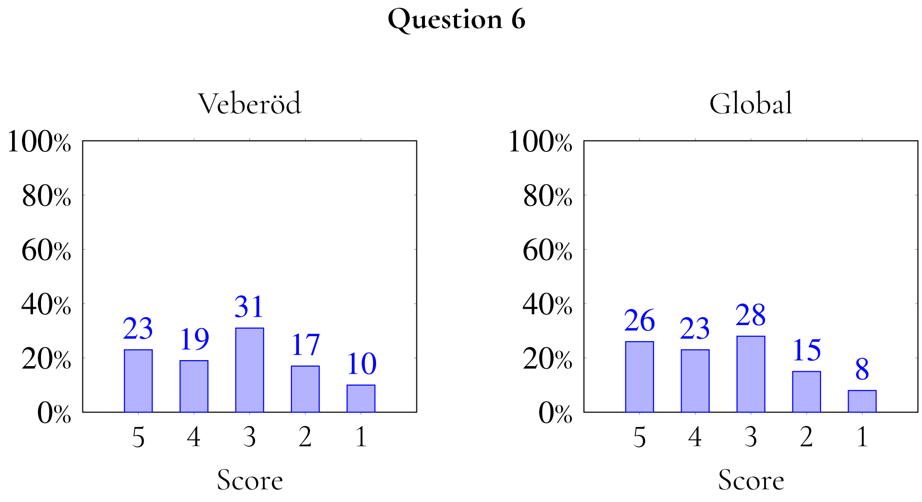


Figure 5.6: I would like to see information, such as the water consumption of my city/town on a 3D map.

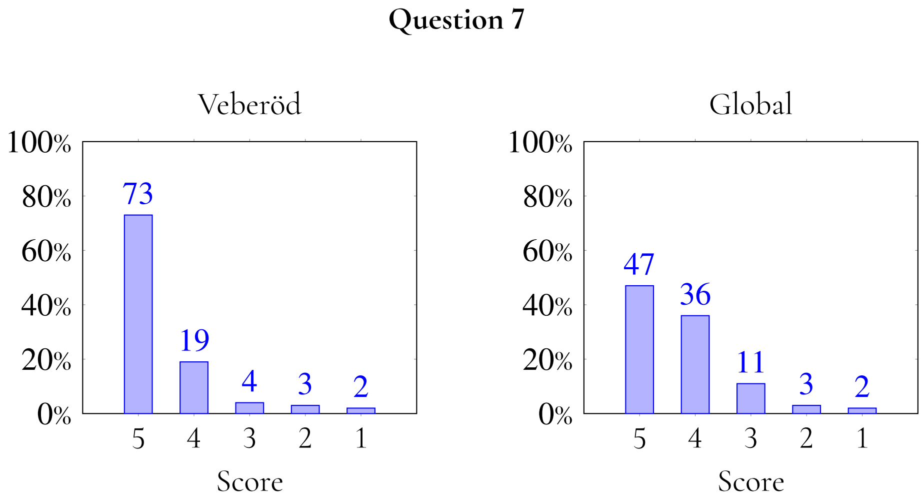


Figure 5.7: I care about the environment.

5.5.3 Town/City suggestions

The last feature that was included in the questionnaire was about being able to suggest potential changes in the town/city by, for example, placing new buildings on a 3D map that represents the town/city, and additionally being able to vote for suggestions. Being able to place buildings on a 3D map could be considered a more experimental feature idea, because it can be hard to know or understand the need of such a feature if it hasn't been practically used before. It could therefore be hard for the respondents to know if such a feature is useful or not. The results from both the Veberöd and the global respondents on question 8 (see Figure 5.8), suggest that there was a slight interest, more than the water consumption mentioned above, with 40.9% on score 5 and 23.6% on score 4, and 28.4% on score 5 and 37.5% on score 4, respectively. However, the interest from respective respondents peaked on question 9 (see Figure 5.9), regarding the ability to vote for various suggestions on how the future town/city should be.

Question 8

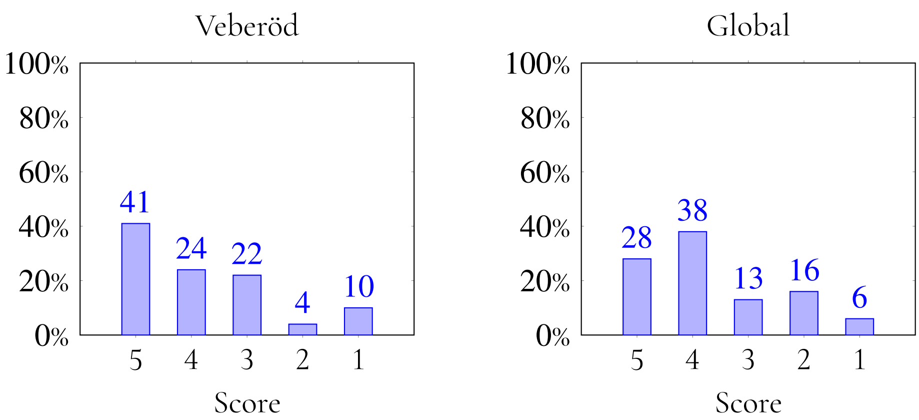


Figure 5.8: I would like to be able to participate and make suggestions directly on a 3D map on how I want my future city/town to be, e.g. by building and placing new buildings.

74.5% of the Veberöd respondents chose score 5, and 51.1% of the global respondents chose score 5, as well as 29.5% on score 4. This indicates that the respondents would very likely want a feature that enables the possibility to vote for various suggestions for the town's/city's future.

Question 9

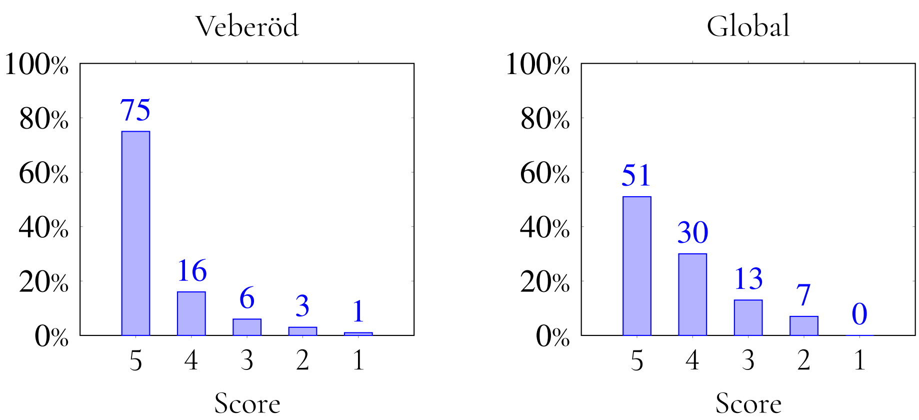


Figure 5.9: I would like to be able to participate and vote for various suggestions on how I want my future town/city to be.

5.5.4 Qualitative section

The questionnaire ended with two qualitative questions, in which the respondents were able to freely write their opinions and give suggestions. The first quantitative question, *What features would you like to have on a 3D map of your town/city?*, received 36 and 33 responses from the Veberöd and the global respondents. The second question, *What information would you like to know about your town/city?* received 42 and 32 responses, respectively. To make the analysis easier, the responses were categorised relative to their subject. As a result, three generalised categorised were created: placing objects, information, suggestions. The *information* category received the most responses, with the majority concerning general information about the town/city in its whole, i.e., opening times and general information for different stores, bus time schedules, and so on. This could explain why viewing information, specifically, about the neighbourhoods scored low. The participants evidently were more interested in viewing more general information about the city/town, than viewing information that could be seen as more private. The respondents may not feel comfortable when the information of one's neighbourhood is available, but are very interested to view information about the town/city in general.

5.6 Conclusion from the Survey

Three key features, i.e., issuing and viewing fault reports, viewing information such as water consumption, being able to suggest and vote for suggestions, were presented in the questionnaire to gain more insight and knowledge about the respondents' feelings towards the features. The results showed a strong interest in fault reports and the ability to vote for suggestions, furthermore a moderately strong interest in giving suggestions. This describes why it is crucial to gather data from users since features, such as viewing water consumption, may look good on paper at first but turn out to be a feature that is not desired among the users. The quantitative data showed a shared interest in the ability to be able to show more general data, i.e., information about the town itself, store information and opening times, and so on, than showing more specific information, such as water consumption for one's neighbourhood, as it could be seen as private information.

5.7 Use Cases

After concluding the survey, the users' needs had been better specified, which in turn let the actual use cases be shaped. The initial use cases, seen in Table 5.1, turned out to match the users' needs and are, therefore, also included in the table, seen in Table 5.2.

Table 5.2: The table displays the use cases for both touchscreen and virtual reality.

Use cases		
Touchscreen		
Use Case	**Actor**	**Basic Flow**
Gaining information of the town.	Town resident.	The resident wants to know what activities are available and their opening times, but she is unsure how to start. She remembers that the city hall has a large touchscreen with information about the town. She walks to the city hall and starts using the touchscreen. She then filters the 3D map to only display information. After navigating around, she has gained enough information.
Adding information.	Shop owner.	The shop owner has recently opened a new shop. He wants the residents to know more about the shop. He remembers that the city hall has a large touchscreen with information about the town. He walks to the city hall and starts using the touchscreen. He then adds a marker where his shop is located and adds information about his shop.
Issue a fault report.	Town resident.	The resident is using the touchscreen in the city hall. She remembers that a road close to her house has a small hole. She then navigates to the hole on the touchscreen and places a marker describing the problem.
Viewing reports.	Municipal employee.	The residents have issued fault reports on the touchscreen platform. The municipal employee filters the view to only display reports. He can then decide which problems have to be resolved.
Giving suggestions.	Town resident.	The resident is using the touchscreen in the city hall. She wishes to have a more colourful town square. She submits her suggestion to the municipality by navigating to the town square on the touchscreen and places a marker describing the suggestion. **Alternative:** She sees a suggestion made by another resident. She reads the suggestion and agrees. She supports the suggestion by endorsing and/or leaving a comment stating her opinion.
Virtual reality		
Issuing a report.	Town resident	The resident wants to report a problem he found in the town, but he thinks that the touchscreen is not accurate enough. Instead, he uses virtual reality to see the digital town in real-world scale. He then places a marker exactly where he found the problem.
Collaborating.	Town resident and municipal employee	The resident wants to demonstrate to the municipal employee and collaborate asymmetrically. The resident navigates around in virtual reality, while the employee has a complete overview of the environment on the touchscreen. The resident places markers that the employee can view, which they can then discuss together.

Chapter 6
Prototyping Phase

6.1 Prototyping

The prototyping process for the town development platform was conducted through two major iterations, the first and second iteration, which in turn were divided into smaller and less pronounced iterations. Unity was chosen as the main software to develop the Hi-fi prototype. Before starting to implement code in Unity, it is crucial to review and test the features and design choices by making low-cost Lo-fi prototypes. It is much easier to adjust and make changes on paper or illustrations than in code. Lo-fi prototypes were presented to the stakeholder, as well as the project's supervisor, to gain feedback before developing the Hi-fi prototype.

6.2 First Iteration

For the first iteration, a Lo-fi prototype was created according to the selected features from the *Conceptual Phase* in the design process. A number of various design alternatives for the town development platform were created, and then quickly presented to a few people that were not directly related to the project, but very delighted to participate and help with their opinions. Thereafter, the ideas were presented to the supervisor for feedback, before proceeding to the next iteration.

6.2.1 Lo-fi prototype

For the first Lo-fi prototype, only the touchscreen interactions were designed, as the VR interactions were harder to portray and also dependent on the touchscreen functions. As it was expected to iteratively adjust and improve the design, it would be more efficient to finish the Lo-fi touchscreen prototype before designing the Lo-fi VR prototype. The illustration for the touchscreen user interface was first created in a web-based Lo-fi prototyping app, *Moqups* (link: [30]), as they offer quick and easy prototyping tools. The user interface for the touchscreen included an overview of the city map, a menu, an information panel, and a marker, seen in Figure 6.1. The menu option, shown as #2 in Figure 6.1, is highlighted in a darker shade of blue because it is selected. The concept is to be able to place different types of markers depending on which menu option is selected. Selecting a marker that has been placed on the map will open an information panel that displays the marker's information.

Figure 6.1: Lo-fi illustration of the user interface for the touchscreen

The three key features that were decided from the *Conceptual Phase* (i.e., issuing fault reports, giving suggestions, and displaying general information), had to be able to be displayed on the information panel. Figure 6.2 shows the potential design of the information panels for each feature. The general *Information* panel on the figure is displaying information on ICA kvantum, with relevant data, such as the address, the opening time, and also the website. If the website button is pressed, the user will be redirected to that website. The *Fault Report* panel is more straightforward, as it only shows the fault description and the problem priority. Lastly, the *Suggestion* panel displays the date it was created on and by whom, as well as the description of the suggestion. The users may also "like" the suggestion by pressing the heart and "comment" by pressing the speech bubble. After selecting a menu option a window with the relevant input data will appear; see in Figure 6.3. Specifically for creating an information marker, the user can fill in the relevant data in the input fields and choose the opening hours, as well as upload an image. After pressing the *Create* button, the user can freely place the marker anywhere on the map. The procedure to create and place suggestion and fault report markers is similar to the information variant (see Figure 6.3), but the parameters differ in the input fields and preference options.

After designing the touchscreen user interface and features, the next step was to apply the same reasoning when designing the VR user interface. However, the asymmetric collaborative functions between VR and touchscreen were not designed, as the limitations and constraints of Unity were unknown during the Lo-fi development.

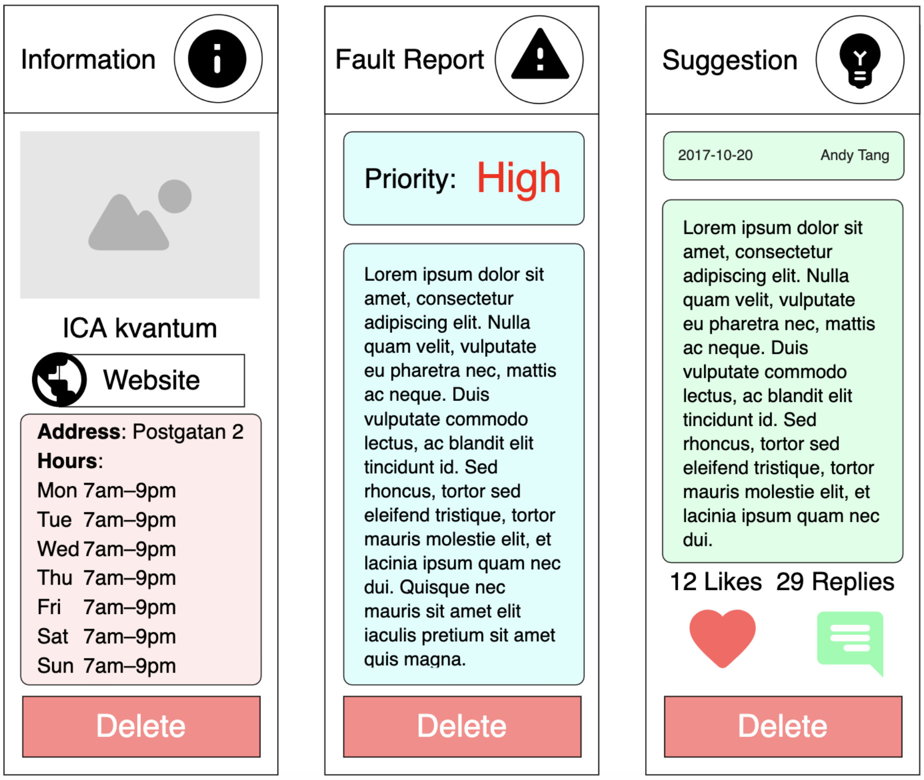


Figure 6.2: Lo-fi illustration of the window to create an information marker

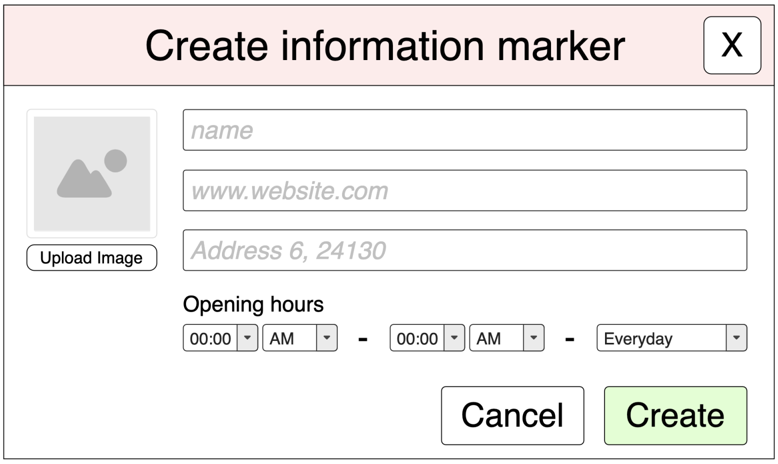
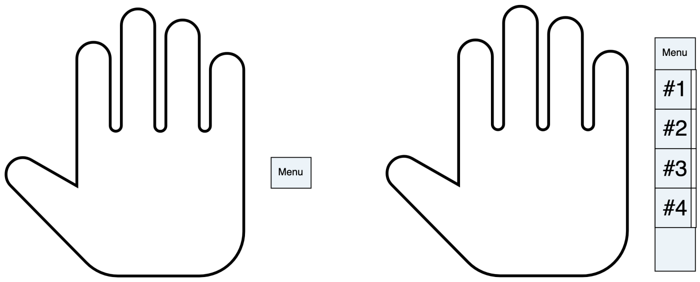


Figure 6.3: Lo-fi illustration of the window to specifically create information markers



(a) The VR menu is closed (b) The VR menu is opened

Figure 6.4: Lo-fi illustration of the VR menu user interface, closed and opened

It would therefore be less complicated and more efficient if the functions were instead designed and developed during the Hi-fi development. The VR user interface itself should have a comparable appearance as the touchscreen to make it easy for the users to switch between VR and touchscreen. But to ensure that the VR view is not blocked by the user interface, the menu would be closed when it is not active, as shown in Figure 6.4 (a). When activated, the menu is opened and displays the different options; see Figure 6.4 (b).

6.3 Second Iteration

A good practice would be to perform a user test for the Lo-fi prototype, but the initial test cases for the Lo-fi prototype were simple enough to be discussed and quickly tested with just the supervisor and the few people outside of the project. Since the project would be implemented in Unity, a tool I am experienced with and which allows for quick prototyping, it would be most efficient to start implementing the foundation of the platform in Unity, and over time iteratively implement more functions directly for the Hi-fi prototype, instead of constructing a Lo-fi prototype for the whole platform. During the implementations of the town development platform in Unity, the project's supervisor and the few people outside of the project were regularly involved by providing their feedback. To conclude the second iteration, a pilot study/test [6] was conducted and performed by the supervisor and the stakeholder. This was to identify possible flaws of the test cases, to later be adjusted and formally written down in the form of a user test plan. In addition, a couple of minor changes had to be made to the project in order to adapt to the adjusted test cases.

6.3.1 Hi-fi prototype

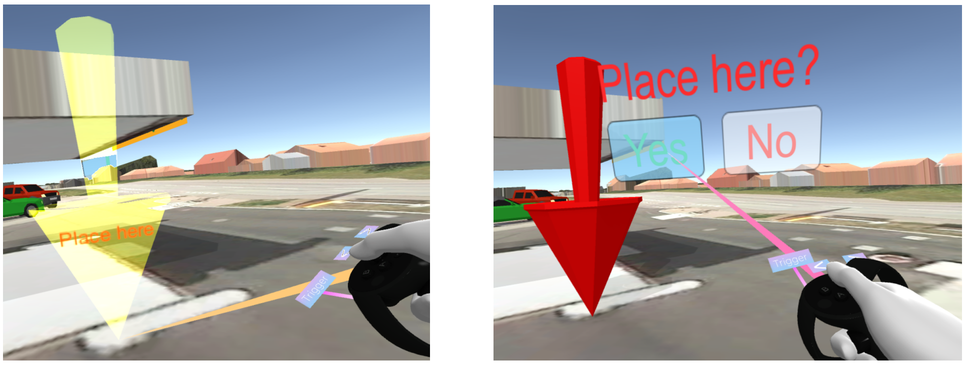
The Hi-fi prototype was developed in Unity. The functionality of the touchscreen could easily be applied to Unity from the Lo-fi illustrations, hence the Hi-fi focused more on the functionality of the VR experience. As VR mainly utilises the movements of the head and hands (controllers) as its input methods when interacting, bodystorming had to be used to generate ideas of the interaction methods and ensure that they are intuitive. An overview of the Hi-fi version of the touchscreen user interface is shown in Figure 6.5.

Figure 6.5: The touchscreen user interface on the Hi-fi prototype

The different colours of the markers represent different types of information: fault reports are blue, suggestions are green, and general information are red. The figure, Figure 6.5, shows the information panel of an information marker that has been selected on the map.

(a) The VR menu is closed (b) The VR menu is opened

Figure 6.6: The VR menu on the Hi-fi prototype, closed and opened



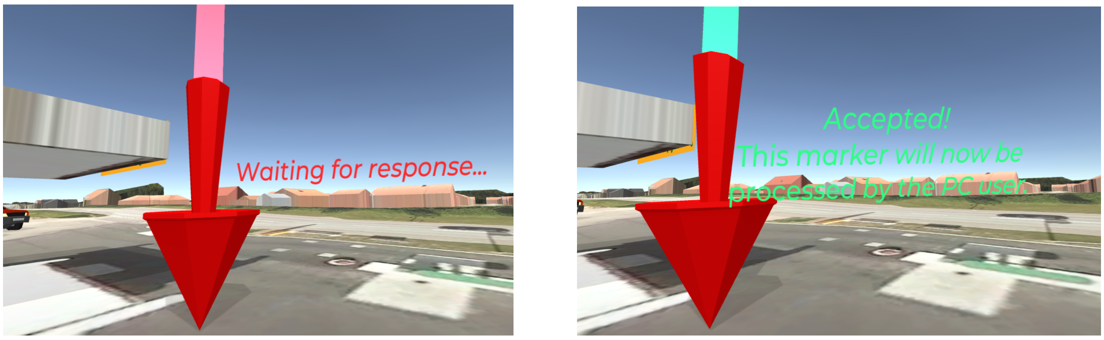
(a) Aiming to place the marker (b) Confirming the placement of the marker

Figure 6.7: Placing the red VR marker

The touchscreen user can also see the current position of the VR user, the pink beacon, and their view in VR, top left display window; both are shown in Figure 6.5. As discussed in the *Lo-fi prototype* section, the VR user interface should resemble that of the touchscreen to improve the usability. It was best done by replicating the touchscreen menu altogether. The Hi-fi VR menu is shown in Figure 6.6, which can be compared with the Hi-fi touchscreen menu seen in Figure 6.5. The most noticeable difference in functionality between touchscreen and VR was the concept of placing a marker. For a touchscreen user, the purpose of markers was to fill in the parameters and then place it on the map. Since it is notably harder to write in VR than on a computer, the VR users did not get the ability to fill in the parameters of a marker; instead the VR user's markers acted as indicators to guide and pinpoint where the touchscreen user should place their markers. This workflow felt more reasonable because the VR user can see the virtual environment in world-space and thus more accurately place markers. Meanwhile, the touchscreen user has full control over the map and the input device for filling in the marker parameters. The markers come in three different colours (green, red, and blue), each representing the different markers that the touchscreen user can place on the map, i.e., suggestion, information, and fault report. To place a marker, the VR user has to select the option in the VR menu, and then aim at a desired position on the ground, as shown in Figure 6.7 (a). After placing the marker, the VR user has to confirm the placement by pressing the “Yes” button next to the marker; see Figure 6.7 (b).

6.4 Asymmetric Collaborative Experience

The VR user has to be able to communicate with the touchscreen user, and to do that both must collaborate by solving a common task. An example of an asymmetric collaborative use case for this project was to let the VR user explore the virtual city and then place a marker on the ground to indicate an interesting point to the touchscreen user; see Figure 6.8 (a).



(a) Waiting for approval by the touchscreen user (red beacon)

(b) Touchscreen user has accepted the request (green beacon)

Figure 6.8: The life cycle of a marker: request, wait, approval

The touchscreen user will immediately receive a notification, asking if they want to be relocated to the VR user’s marker. If the touchscreen user accepts the request, the touchscreen user will automatically be moved to that location, and the VR user will be notified by the marker, as seen in Figure 6.8 (b). Figure 6.9 shows the touchscreen user’s view after accepting the VR user’s request and being automatically moved.

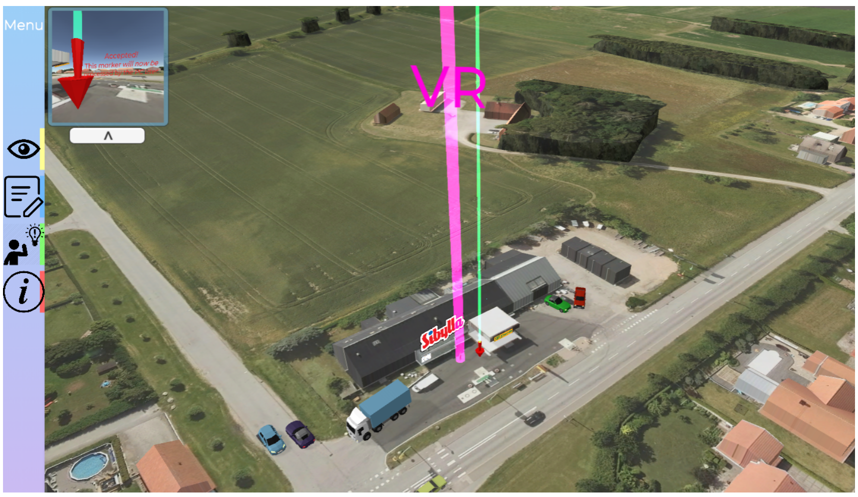


Figure 6.9: The touchscreen view is displaying the VR user (pink beacon) and the red marker (green beacon)

The touchscreen user’s next step is to identify which colour the marker is, in this case red, which represents the touchscreen user's information marker. The touchscreen user will then select the *Create information marker* option from the menu, and then ask the VR user for information to fill in the parameters. After filling in the correct data, the touchscreen user can replace the VR user's marker with their own and newly created information marker by clicking on the red marker, which is illustrated in Figure 6.10.

(a) VR user is waiting for the red marker to be replaced

(b) The red marker has been replaced with a red marker

Figure 6.10: Process from red marker to red information marker

Chapter 7

Evaluating Phase

7.1 Usability testing

The user test plan for this project consisted of 3 parts (see table 7.1): briefing, tasks, and debriefing. The briefing session gave the participants a brief introduction to the project, as well as the structure of the user test, following by a short questionnaire to let the participants fill in their profile information. The second part was a collection of tasks that were structured based on the issues and questions that the user test aimed to answer. Lastly, the debriefing session was to further gain insights and knowledge about the user experience of the project. The debriefing started with a post question questionnaire to obtain quantitative data and ended with an interview question to let the participant freely express their opinions.

Table 7.1: Procedure table with descriptions for each step and the estimated time required.

Procedure			
Part	**Step**	**Description**	**Time**
Pre	Briefing	- Receive participant. - Inform about the project and the user test. - Profile info of the participant (Quantitative).	5-10 min
During	Tasks	- Instruct the participant through the tasks.	20-35 min
Post	Debriefing	- Debriefing questions (Quantitative/Qualitative).	5-15 min
Total			**30-60 min**

7.2 User test

The user test took place in the VR lab of IKDC at the Faculty of Engineering at Lund University. Initially, the user test was meant to be done pairwise, but for safety reasons during the COVID-19 pandemic the test was instead performed one by one. To circumvent the problem, the first half of the participants would begin the tasks with the touchscreen, while the test moderator used the HMD (VR). Thereafter, the participants would switch to HMD (VR) and the test moderator to the touchscreen. The other half would start with the HMD (VR) and later switch to the touchscreen. In total, 12 participants completed the user test. The user test was performed on a *FlatFrog* touchscreen [31] and on an Oculus Quest; see Figure 7.1 for the user test setup.

Figure 7.1: The user test setup. Figure shows a FlatFrog touchscreen, a laptop, and an Oculus Quest

7.2.1 Briefing

Upon arrival, each participant was introduced to the purpose of the project and a brief summary of the user test. The participants were assured that the test could be stopped at any time if they did not feel comfortable and that it was okay to make mistakes, as the object to test was the project and not the participants themselves. A questionnaire was presented, in which the participants had to answer 5 profile questions, such as age, gender, experience with playing games, experience with VR, and their most used gaming device. This was to get an overall understanding of the participants' previous experiences with technology, specifically games and VR, as a part of the test would be in VR.

7.2.2 Tasks

The user test consisted of 24 tasks which were divided into 4 categories: touchscreen interactions, touchscreen interactions (Asymmetric Collaboration), HMD (VR) interactions, and HMD (VR) interactions (Asymmetric Collaboration) (see Appendix A). The tasks were structured based on the issues/questions that the test aimed to answer. The tasks consisted of a task ID, the task itself, sub-tasks which described the steps, and lastly, completion and max amount of errors, which described when the task could be considered "successfully completed" within the max amount of errors. The definition of an error in the user test was when the user in some sense expected that it was the correct interaction when it was actually wrong. Clicks and drags to quickly navigate through the system were not considered to be faulty clicks, even though it was not the correct choice to complete the task. Ultimately, the definition of an error depended on the task and the participants' reasoning, as they were told to think aloud.

7.2.3 Debriefing

Debriefing was done after the tasks to gain further insight and knowledge about the user experience. The debriefing started with a post-survey to gain quantitative data, which the participants had to fill in. The questions had a Likert scale of a range from 1 to 5, where the representations of the numbers are shown below together with the questions:

- What was your first impression of the application? (Very poor - Very good)
- How easy were the interactions in PC? (Very poor - Very good)
- Which interaction method did you prefer? (Mouse - Touch)
- How easy were the interactions in VR? (Very poor - Very good)
- Were the HMD (VR) features relevant for this kind of usage? (No, not at all - Yes, absolutely)
- What is your impression of working between VR and PC? (Very poor - Very good)
- Is it useful to work between VR and PC in city planning? (VR/PC should be separated - I see the usefulness)
- Can you see the interactions between VR and PC being useful in other systems than city planning? (No, not at all - Yes, absolutely)

To gain qualitative data, the debriefing ended with an interview question, *Do you have any other input/thoughts about the application?*, to hear more about the participants' overall experiences and thoughts about the asymmetric experience.

7.3 Results from the User Testing

The data collected from the different parts of the user test will be discussed and presented in this section.

7.3.1 Profile data

Every participant (n=12) completed the profile questionnaire. The average age was 31, and the gender distribution was 9 (75%) male and 3 (25%) female. Prior VR experience was well distributed: 6 (50%) of the participants had not used VR before, and 5 (41.7%) and 1 (8.3%) had used VR a few times and many times, respectively. However, the majority had great experience with playing games, with 7 (58%) on 5, and 3 (25%) on 4. Lastly, the most used entertaining system was computer (n=5, 41.7%), but console and mobile were not far off with 4 (33.3%) and 3 (25%), respectively. In conclusion, the average participant that completed the user test had a somewhat great experience with playing games but may or may not have tried VR prior to the test.

7.3.2 User test data

Although half of the participants started with the touchscreen and the other half with the HMD (VR), the test results between the two groups were not significantly different. The user test could therefore be evaluated without taking into account that the user test was divided into two groups. Despite the test having a total of 24 tasks, only the tasks that reached the maximum or close to the maximum amount of errors will be presented; see Table 7.2, and see Appendix A for the full task list.

7.3.2.1 Touchscreen interactions

The *Touchscreen interactions* included both touch and mouse interactions. To switch from touch to mouse interactions the user must first select a mouse interaction option; see Figure 7.2. 11 (91.7%) of the participants failed to understand that at first try, as they thought switching between touch and mouse interactions would happen automatically by either swiping with the finger or by moving the mouse while holding down the mouse button. As a result of completing the first mouse interaction task, the other mouse tasks went smoothly. The next common obstacle was hiding the mouse menu which contained the various mouse interaction options. This could be done by pressing the arrow pointing downwards above the mouse menu; see Figure 7.2. 6 (60%) of the participants had trouble understanding or finding the button, and instead tried to press outside of the menu bar to hide it. The arrow was, in most cases, misinterpreted as the letter "V".

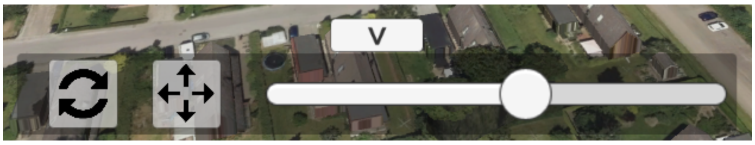


Figure 7.2: The menu bar with options for mouse interaction, including the down-pointing arrow to hide the menu

The touch interactions were more successful, considering that every participant is used to interacting with their smartphones. However, as a result 11 (91.7%) of the participants were not able to complete task 6, *Rotate the view using touch*, because they were expecting to be able to rotate by doing a rotating motion with two fingers on the touchscreen, as that is the most common way to rotate with touch. To complete the task the user has to swipe with 2 fingers

Table 7.2: The table displays the tasks which reached the maximum or close to the maximum amount of errors.

Tasks with errors				
Touchscreen interactions				
Task ID	**Task**	**Sub-tasks**	**Completion**	**Max amount of errors**
1	Navigate using a mouse.	1.1 Press the "Drag" button. 1.2 Drag the screen in any direction while mouse button is down.	The view is moved in any direction.	1
4	Hide the mouse menu.	4.1 Press the "hide" button.	The mouse menu is hidden.	1
6	Rotate the view using touch.	6.1 Swipe with 2 or more fingers on the screen in any direction.	The view is rotated in any direction.	3
14	Show all placed markers.	14.1 Press the yellow menu button.	All coloured markers are displayed.	2
HMD (VR) interactions				
1	Navigate by rotating.	1.1 Press the joystick left or right.	VR view is rotated in any direction.	2
2	Navigate by tele-porting.	2.1 Tilt the joystick forward. 2.2 Release the joystick.	VR has moved to the teleport marker.	2
3	Open the fast travel menu on the bus ...	3.1 Aim the controller at the "Open!" button. 3.2 Press the "trigger" button. 3.3 Aim at any window (image). 3.4 Press the "trigger" button.	VR has moved to selected fast travel destination.	4
4	Open and close the VR menu.	4.1 Open the VR menu by pressing and holding the "grab" button. 4.2 Release the "grab" button to close the VR menu.	VR menu is closed.	3
6	Place a VR marker.	6.1 Open the VR menu. 6.2 Aim at any colour and press the "trigger" button. 6.3 Aim at the ground. 6.4 Press the "trigger" button to place.	VR marker is placed on the ground.	3

on the touchscreen, which worked well after telling the participants how it was supposed to be done. After the participants grasped the basic interaction methods using the mouse and touch, the next step was to interact with the main menu. Placing markers and switching between markers was relatively easy, as barely anyone made mistakes.
Though, when the participants were asked to display all the markers, simultaneously, only 6 (50%) made it the first try. To display all the markers, the user has to press the *eye* icon on the main menu. The participants did not understand the *eye* icon: instead, they thought the menu button acted as toggles that would display the markers until they are untoggled.

7.3.2.2 HMD (VR) interactions

Switching to HMD was a challenge at first for some participants, mainly due to no prior experience. As discussed in the previous section (see section *Profile data*), the profile data showed that 50% of the participants had no prior VR experience, and only one had used VR many times. The fact that the *HMD (VR) interactions* had more errors was therefore expected.
To start off, the user has to rotate their VR view by tilting the joystick left or right. 5 (41.7%) of the participants could not complete the task without errors. They were not used to the controller and could not guess the purposes of the buttons, or they did not understand the concept of being able to rotate in a VR environment. Finding teleport button was much easier after knowing how to rotate with the joystick, as teleportation was also done by tilting the joystick. By tilting and holding the joystick forward, a teleportation marker – which the user can teleport to – will be displayed on the ground where the user is aiming; see Figure 7.3.
The problem occurs when the user has to execute the teleportation by releasing the joystick, which 7 (58.3%) of the participants failed to realise.

Figure 7.3: The teleportation ray and marker are shown by tilting and holding the joystick forward

The participants were later asked to use the *fast travel* option, which they could do by interacting with the bus at the starting point. To interact with the bus menu, the user must aim the controller towards the menu. A laser pointer will appear if the user has aimed the controller correctly. 7 (58.3%) of the participants struggled with interacting with the bus menu at first. They either thought the teleportation ray, seen in Figure 7.3, would function as a laser pointer to interact with the menu, or they simply did not understand the concept of being able to aim the controller like a laser pointer. The more experienced VR users knew immediately that aiming the controller towards the menu would trigger the interactions. To traverse back to the starting point, the user may use the *return to bus* option in the VR menu, which is accessible by holding the *grab* button of the VR controller; see Figure 6.6. When asking the participants to return to the starting point through the VR menu, every participant (n=12, 100%) tried to open the VR menu by clicking the *grab* button. This was, unfortunately, not enough to trigger the desired action, as the drop-up animation to make the VR menu appear was proportional to how long the button was held down. The interaction with the VR menu was effortless, as the participants had already interacted with the bus menu, which had the same type of interaction methods. One of the key functions, task 6 (*Place a VR marker*), went partly good. The participants navigated through the VR menu and selected the correct option with ease. However, 8 (66.7%) of the participants had problems with placing the marker on the ground after selecting that option. To place a marker, the user has to aim the laser pointer – which appears after selecting the *place marker* option – on the ground, and then press the *trigger* button. Since the laser pointer is visually a straight line and not curved as the teleportation ray (see Figure 7.4), the participants struggled to understand that the laser had to be aimed at the ground. Instead, the participants continued to press the menu option repeatedly in the hope that it would work as they expected.

(a) Not aiming at ground

(b) Aiming at ground

Figure 7.4: The laser pointer not aiming and aiming at the ground

7.3.2.3 Improvements

By observing the participants, I could identify which interactions that needed improvements to increase the usability.

- Navigate using a mouse.
  - **Problem:** User is expecting to be able to move the view without selecting the *move* option.
  - **Fix:** User should be able to move the view without having to select the *move* option.
- Hide the mouse menu.
  - **Problem:** User does not understand the design of the arrow pointing downwards. Is mistaken as the letter "V".
  - **Fix:** Change the icon to something that is easier to understand.
- Rotate the view using touch.
  - **Problem:** User is expecting the view to rotate when doing a rotating gesture with 2 fingers on the touchscreen.
  - **Fix:** Replace the *swipe to rotate* gesture with a rotating gesture.
- Show all placed markers.
  - **Problem:** User does not understand the *eye* icon; instead, they expect the menu options to work as toggles.
  - **Fix:** Make the menu options toggleable, and replace the *eye* icon with something that is easier to understand.
- Navigate by rotating.
  - **Problem:** User does not understand the concept of being able to rotate, nor do they understand the buttons of the VR controller.
  - **Note:** The VR controller is using standard key mapping for Oculus.
  - **Fix:** Instruct the user beforehand.
- Navigate by teleportation.
  - **Problem:** User does not release the joystick to execute the teleportation.
  - **Note:** The VR controller is using standard key mapping for Oculus.
  - **Fix:** Instruct the user beforehand.
- Open the fast travel menu on the bus ...
  - **Problem:** User does not understand the concept of aiming the controller towards the menu as a laser pointer.

  – **Fix:** Make the menu options bigger for easier aiming, and in addition, let a first-time user go through a quick and fun tutorial in the VR environment.

- Open and close the VR menu.
  – **Problem:** Drop-up animation to make the menu appear is proportional to the time the *grab* button is held down.
  – **Fix:** Trigger the animation by clicking instead of holding down the button.

- Place a VR marker.
  – **Problem:** User does not understand that the laser pointer, which appears after selecting the *place marker* option, should be aiming at the ground.
  – **Fix:** Make the laser pointer into a curving ray that automatically aims at the ground, or make it more obvious that the pointer should be aimed at the ground with an informational pop-up (that does not hinder the user's view).

- General/ETC.
  – **Problem:** Some colour choices and icons were misinterpreted.
  – **Fix:** Adjust colours and icons to be more relevant for their purposes. In the best case, but not most optimal, construct a quick user test for just the design.

7.3.3 Post-test data

After the user test, the participants had gotten enough experience with working in an asymmetric virtual environment and were ready to complete the debriefing survey and, lastly, answering the interview question, *Any other inputs/thoughts about the application, e.g., working between VR and a touchscreen*. The survey contained 8 questions, each with a range from 1 to 5 but with different values.

7.3.3.1 Debriefing questionnaire

As seen on Figure 7.5, the first impression of the application was okay, which was expected as the focus when developing the app was more towards functionality and usability than pure design. With more time, another iteration would have been made, which would have made it possible to make the application more attractive. But for this user test, the current version of the project was enough to achieve a good conclusion. Since the users could choose between either using a mouse or a touchscreen, it was of interest to find out which they preferred. In question 3, the column chart (see Figure 7.6) illustrates that the mouse and touch interactions received comparable responses. The touch was, however, slightly more favoured, as touch interactions felt more relevant and useful on a big touchscreen and for the tasks that the participants had to complete. Nonetheless, some participants preferred to use a computer with a mouse and a keyboard to accomplish big tasks, as they thought touch was mainly useful for manipulating the view and not for professional use. When comparing the ease of interacting in PC and VR, question 2 in Figure 7.5 and question 3 in Figure 7.6, the responses for VR interactions were more dispersed than the PC interactions. As discussed in the *Profile data* section, 50% of the participants had no prior experience with VR, which resulted in difficulty of understanding the concepts and interaction of VR. However, some interaction decisions were, despite having prior experience with VR, hard to understand. Yet, question 5, *Were the HMD (VR) features relevant for this kind of usage?* (see Figure 7.7), suggests that the overall experience with VR was good and the features were relevant.

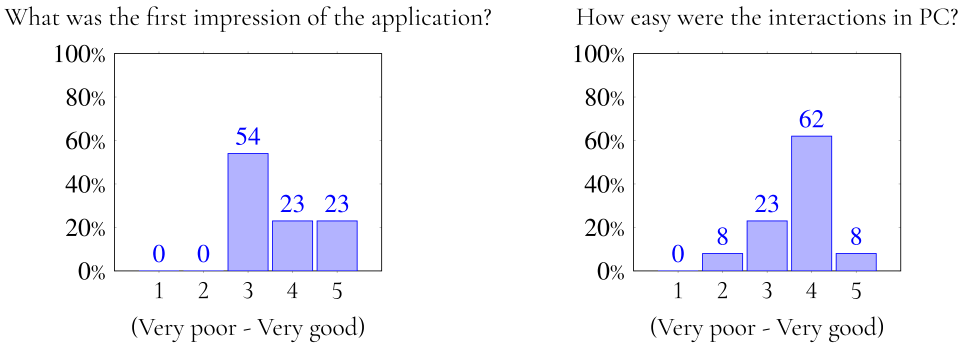


Figure 7.5: Debriefing survey question 1-2

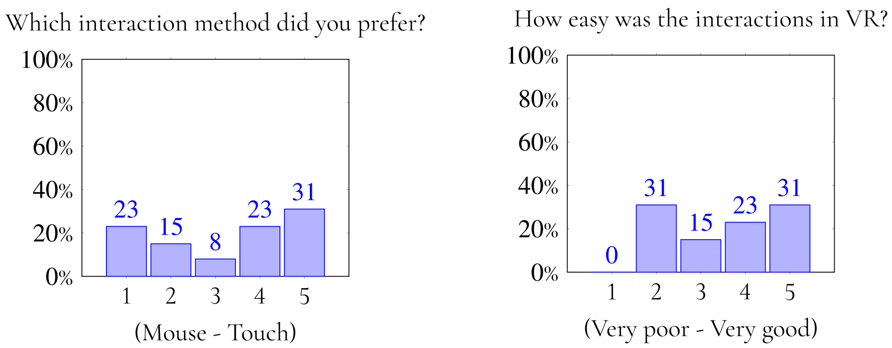


Figure 7.6: Debriefing survey question 3-4

As the main purpose of this test was to evaluate the asymmetric collaborative experience with VR and a touchscreen, the last few questions aimed to answer that.

The general impression of working between VR and PC was good, with a majority of the responses (46%) on score 4; see question 6 in Figure 7.7. Lastly, question 7 and 8 summarised the whole experience and were essential as the questions are part of the purpose and goal of this project; see Figure 7.8. The majority of the participants had a good impression of working between VR and PC in city planning, as 69% of the responses, when asking about the usefulness (see question 7, Figure 7.8), was on score 5. Question 8 was similar to question 7, but instead of asking specifically about city planning, the respondents were asked whether they could see the asymmetric experience between VR and PC being useful in other systems or not, in which every participant responded with a score of 5.

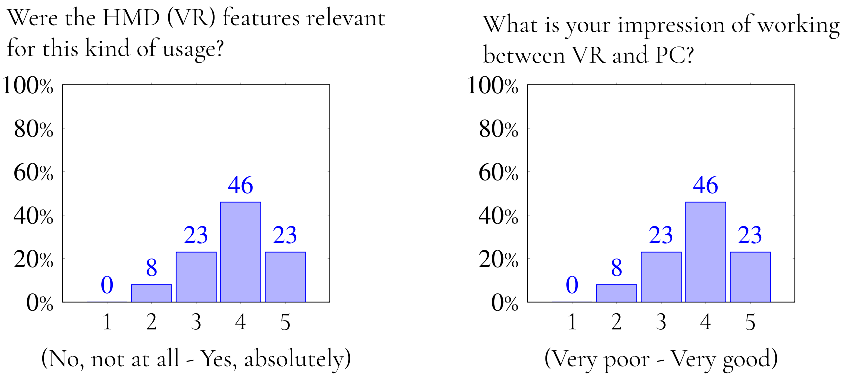


Figure 7.7: Debriefing survey question 5-6

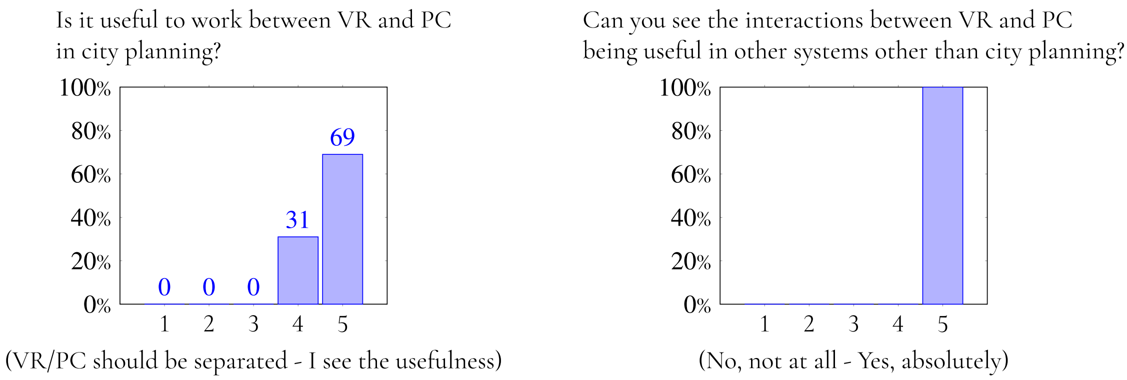


Figure 7.8: Debriefing survey question 7-8

7.3.3.2 Debriefing interview

The participants were asked a final question before concluding the user test, *Do you have any other input/thoughts about the application?*, to which the majority of the participants answered that working between VR and PC could be a potential and useful tool. They liked the idea that the VR user can see the environment in real-world scale, while the touchscreen (PC) user has an overview of the whole platform. However, the participants questioned whether the collaboration between VR and PC in city planning was useful or not, despite the fact that the debriefing survey on usability had a high score, with the reasoning that the essential functions could have been performed entirely with only the touchscreen (PC). The participants were sure that it would be more useful if a system took full advantage of the workflow between VR and PC and were developed for just that purpose. An example of a system that was discussed was a construction system, where the VR users can build while the touchscreen (PC) users have a full overview of the map. Some participants could also see augmented reality (AR) being used rather than VR for this purpose.

7.4 Conclusions from the Evaluating Phase

The overall workflow throughout the whole user test worked well, although half of the participants did not have any prior experience with VR. The user test started with navigation tasks to enable the participant to get comfortable with the system before proceeding to the essential collaborative tasks. For the collaborative tasks, the participants had to work together with VR or PC, depending on which they used. This ultimately gave the participants an idea of how a workflow is between VR and PC, and they could thereafter complete the debriefing survey. The overall experience working between VR and touchscreen (PC) was good, as the survey questions regarding the asymmetric collaborative experience scored high by the respondents. Lastly, in the debriefing interview, the participants expressed that they could see the concept of working between VR and PC being useful, given that the system would take full advantage of the workflow and be developed for just the purpose of being an asymmetric collaborative virtual environment.

Chapter 8
Discussion and Conclusion

8.1 Research questions

In the *Purpose and Goal* section, a number of research questions are presented. The questions will be discussed and answered in this section.

Question 1: *How useful is an asymmetric collaborative experience with virtual reality and a touchscreen as a tool for planning smart towns?*
To obtain a good answer, the thesis was shaped from the beginning with this question in mind. The challenge was to extend the already provided proposal of creating a city planning platform and come up with a way to combine VR with a touchscreen, together with the city planning platform. The stakeholder had given possible and desired features for the platform. However, through a user-centred design perspective, it was crucial to gather information from the potential users to understand their needs. The responses suggested that there was a need for displaying general information about the city, giving suggestions, and placing fault reports. These functions would be the main features of the platform, and the next step was to determine how to implement these for both VR and a touchscreen in a way that would make sense for this purpose.

To answer this question, the interactions between VR and a touchscreen (PC) had to be reasonable and meaningful to provide the participants with a good perception of the workflow between VR and a touchscreen. When the platform was ready to be used as a tool to gather user test data, a user test was conducted to let the participants experience an asymmetric collaborative town development environment. In this way, the participants would have gained enough knowledge to be able to reflect whether an asymmetric collaborative environment is useful or not in a city planning platform or in general. A post-test survey and a debriefing interview were enough to provide sufficient data for evaluation and to conclude the test. The participants were satisfied with the test and could see the usefulness of working between VR and a touchscreen. However, a few participants were questioning whether it was useful for a city planning platform or not since most of the features were already accessible through the touchscreen. The purpose of the VR user could be extended into the touchscreen, making the VR user meaningless for the platform. The same participants could, despite that, see the usefulness of collaborating asymmetrically between two media. The concept of the VR users being able to see the virtual environment in world-size, while other users can collaborate with the VR users on a touchscreen with a full overview of the environment, was appealing. To conclude, *an asymmetric collaborative experience with virtual reality and a touchscreen as a tool for planning smart towns* is moderately useful; the participants understood the potential and the usefulness, but they would also want to see the concept being applied to other systems as well, as they think that it could be used as a professional tool given a suitable system that could take full advantage of the asymmetric collaborative interactions.

Question 2: *How can such an approach be designed with usability in mind?*
Throughout the whole prototyping process, the goal was to make the interactions as easy to use as possible. A good approach was to start with designing a Lo-fi prototype to save time when developing the Hi-fi prototype in Unity. Since a good portion of the interactions would be through VR, bodystorming was necessary to generate ideas and potential interaction methods, as VR requires physical movements and gestures. However, as reinventing the wheel is not optimal nor efficient, the default key mapping for the VR controller was used unless a function needed to change the default functionality. A similar approach was taken when designing the functions of the touchscreen, since fundamental interactions would be easier to understand if they resembled commonly used designs. It is good to periodically conduct a pilot test or a small user test to evaluate the design, to gauge whether it is easy to use or not. Since the resources and time were limited, the quick and periodical user tests were mostly with close by participants. When the design and functions were mostly complete, a pilot test was conducted with the stakeholder and the supervisor to gain feedback before the final and most formal user test. During the user test, every mistake made by the participants was observed to later be evaluated. After the user test, the design choices that the participants had problems with understanding were adjusted accordingly to make the system easier to use.

Question 3: *How intuitive are interactions in a collaborative virtual environment with Virtual reality and a touchscreen?*
During the user test, a few design choices were hard to understand (mainly the VR interactions). As mentioned in the *Touchscreen interactions* section, half of the participants had no prior experience with VR, resulting in some having a hard time to understand the VR concepts. Because a part of the thesis was to develop and evaluate a city planning platform, the project did not have a specified user group; therefore, all participants were of interest, including those with no prior VR experience. As discussed in Question 2, most of the fundamental VR and touchscreen interactions were mostly easy to use, as the interaction methods often resembled those of other systems. But were the interactions in a collaborative virtual environment with Virtual reality and a touchscreen intuitive? The purposes of the VR and touchscreen functions were relevant and easy to understand, as illustrated in the post-test survey (section *Debriefing questionnaire*). But in some cases the purposes of the asymmetric collaborative functions had to be explained, as the concept of collaborating between VR and a touchscreen in a city planning platform did not feel natural to some. If it would have been

a more relevant system with a clearer purpose when collaborating asymmetrically, the participants would have more likely understood the concept without needing an explanation. To conclude, the interactions themselves were mostly easy to use and intuitive, as some resembled commonly used interaction methods. The asymmetric collaborating functions were not entirely intuitive, mainly because the participants could not perceive why they were needed in a city planning platform, thus making it harder to understand the purpose of the feature. They would have more likely understood the purpose and thus find it more intuitive if the platform was more relevant for this purpose.

8.2 Obstacles and Error sources

During the thesis project, a couple of obstacles hindered development. An external obstacle that impacted the whole process negatively, was the ongoing *COVID-19* pandemic [32]. As a result, the majority of the development time was spent at home. As the available computer was not entirely *VR ready* [33], i.e., optimal for the use of VR, the development time suffered because of performance issues. Another obstacle was the way Unity handles event handlers [34]. Unity only supports one event handler at a time, making it hard to combine and use VR and PC interactions simultaneously, as they require one event handler each. It was also not possible to debug and test the touch interactions at home, since the touchscreen was located in the VR lab of IKDC at the Faculty of Engineering at Lund University. The user tests also suffered because of *COVID-19*, as the user test was meant to be performed in pairs, instead of one by one.

The first questionnaire that was sent out globally did not ask whether the respondent lived in a city or a village. In the data analysis, an assumption was made that most of the global respondents lived in a city.

Since the decision of which key features to include in the city planning platform were strictly according to the respondents' needs, the platform's fundamental functions were useful on paper. However, in certain cases, users don't know what they really want before the product is presented. Given that the key functions would have been decided independently of the users' needs, the platform would have gotten more relevant functions to better achieve the thesis goal and purpose, i.e., evaluating the interactions and usability in an asymmetric collaborative virtual environment. It would, in turn, have improved both the experience of the user tests and the results of the thesis.

The main purpose of this thesis was not to test the fundamental VR interactions but to test the asymmetric collaborative interactions. By constructing a user test for the whole VR experience, some participants had trouble understanding the fundamental VR interactions, which could affect their perception of the more complicated tasks, the asymmetric collaborative interactions. The default VR functions could have been explained beforehand.

8.3 Future work

For future work, the city planning platform could be extended with augmented reality, enabling the AR users to walk in the physical world while interacting with the touchscreen user, which is stationary and has an overview of the whole city in real-time. In that way, the asymmetric collaboration between the users would feel more useful and reasonable. For future work with VR and a touchscreen, the asymmetric collaborative environment could instead be a constructing platform in which the VR users can construct and design buildings as their environment is in real-world scale, while the touchscreen user has a full overview.

The new hand-tracking feature for VR came with the Oculus Quest, which was first meant to be used in this project, as the hand-tracking interactions resembled those of augmented reality. By using hand-tracking, the augmented reality interactions could also be evaluated, at least to some extent, making it possible to extend the experience into augmented reality with ease. Implementing hand-tracking could therefore be a potential future work.

8.4 Final Conclusion

The structure and the development of the thesis have been a result of a user-centred design process. The purpose of the thesis was to identify if asymmetric collaborative interactions between VR and a touchscreen could be used as a tool for professional use. Prototypes were constructed to test the purpose, then iteratively adjusted and improved according to the test results. The obtained data from the research suggests that the concept of collaborating asymmetrically between VR and a touchscreen is moderately useful – only moderately, since the usefulness was not obvious in a city planning platform, but the overall concept was well-received. Given a platform that is developed solely for an asymmetric collaborative environment, the potential would increase tremendously.

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Appendices

Appendix A
Observer Protocol (Tasks)

Observer Protocol - Observer:________________ Participant:________________

Date (yyyy-mm-dd):________________

Touchscreen interaction				
Task ID	**Task**	**Sub-tasks**	**Completion**	**Max amount errors**
1	Navigate using a mouse.	1.1 Press the ‘’Drag” button. 1.2 Drag the screen in any direction while mouse click is down.	The view is moved in any direction.	2
Comments:				
2	Rotate the view using a mouse.	2.1 Press the “Rotate” button. 2.2 Drag the screen in any direction while mouse click is down.	The view is rotating in any direction.	1
Comments:				
3	Zoom in/out using a mouse.	3.1 Press and drag the slider.	The view is zooming in or out.	1
Comments:				
4	Hide the mouse menu.	4.1 Press the “hide” button.	The mouse menu is hidden.	1
Comments:				
5	Navigate using touch.	5.1 Drag with 1 finger on the screen in any direction.	The view is moved in any direction.	2
Comments:				
6	Rotate the view using touch.	6.1 Swipe with 2 or more fingers on the screen in any direction.	The view is rotating in any direction.	3
Comments:				

7	Zoom in/out using touch.	7.1 Pinch or stretch 2 fingers on the screen.	The view is zooming in or out.	2
Comments:				
8	Place a “Fault report” marker.	8.1 Press the blue option in the menu. 8.2 Press the “+” button (did they read the message?). 8.3 Fill in the fields. 8.4 Choose either mid or high priority. 8.5 Press the “Create” button 8.6 Place the marker on the map (did they read the message?).	Marker is placed on the map.	5
Comments:				
9	Select and unselect a marker.	9.1 Press on a marker. 9.2 Press outside of the marker	Marker is unselected.	1
Comments:				
10	Delete a marker	10.1 Press on a marker. 10.2 Press “Delete”.	Marker is deleted.	1
Comments:				
11	Place a “Info” marker.	11.1 Press the red option in the menu. 11.2 Press the “+” button (did they read the message?). 11.3 Fill in the fields. 11.4 Press the “Upload Image” button. 11.5 Select and open any image. 11.6 Change “Opening hours” to 6AM and 9PM. 11.7 Press the “Create” button 11.8 Place the marker on the map (did they read the message?).	Marker is placed on the map.	6
Comments:				
12	Enlarge an “Info” marker image, and close it.	12.1 Press on a red marker. 12.2 Press on the image. 12.3 Press the “X” to close.	Image is closed.	2

Comments:				
13	Filter to another colored marker.	13.1 Press any of the colored menu buttons to filter to that color.	The selected color is displayed.	2
Comments:				
14	Show all placed markers.	14.1 Press the yellow menu button.	All colored markers are displayed.	2
Comments:				

Touch-screen interaction (Asymmetric Collaboration)				
Task ID	**Task**	**Sub-tasks**	**Completion**	**Max amount errors**
1	Accept VR request to be moved to a VR marker.	Pre: Wait for notification to appear. 1.1 Press the ‘’Accept” button.	The view is moved to the VR marker.	1
Comments:				
2	Replace the colored VR marker with a colored marker.	2.1 Select the correct color on the menu. 2.2 Fill in the information for that option. 2.3 Place the marker on the VR marker to replace it.	The VR marker is replaced with a marker.	1
Comments:				

HMD interaction				
Task ID	**Task**	**Sub-tasks**	**Completion**	**Max amount errors**
1	Navigate by rotating.	1.1 Press the joystick left or right.	VR view is rotated in any direction.	2
Comments:				
2	Navigate by teleporting.	2.1 Tilt the joystick forward. 2.2 Release the joystick.	VR has moved to the teleport marker.	2

Comments:				
3	Open the fast travel menu from the bus and fast travel to any location.	3.1 Aim the controller at the "Open!" button. 3.2 Press the "trigger" button. 3.3 Aim at any window (image). 3.4 Press the "trigger" button.	VR has moved to selected fast travel destination.	4
Comments:				
4	Open and close the VR menu.	4.1 Open the VR menu by pressing and holding the "grab" button. 4.2 Release the "grab" button to close the VR menu.	VR menu is closed.	3
Comments:				
4	Travel back to the bus.	4.1 Open the VR menu. 4.2 Aim and press the "bus" icon with the "trigger" button.	VR is back to starting position (Bus).	1
Comments:				
5	Place a VR marker.	5.1 Open the VR menu. 5.2 Aim at any color and press the "trigger" button. 5.3 Aim at the ground. 5.4 Press the "trigger" button to place.	VR marker is placed on the ground.	3
Comments:				
6.	Navigate through the VR marker menu. Then, request the PC to be moved to the marker.	6.1 Press the "Yes" button with the "trigger". 6.2 Press the "Yes" button with the "trigger".	VR marker is sending out a beacon. Alt. VR marker is accepted by PC.	1

Comments:		

HMD interaction (Asymmetric Collaboration)				
Task ID	**Task**	**Sub-tasks**	**Completion**	**Max amount errors**
1	Place a red VR marker in any fast travel location.	1.1 Select a fast travel destination. 1.2 Teleport to the information wall. 1.3 Place a red marker on the ground, close by.	Red VR marker is placed close the to information wall.	1
Comments:				
2	Request the PC to move to the VR marker and wait for the PC to replace the VR marker.	2.1 Navigate through the red VR marker menu and request to move the PC user. 2.2 Wait for the PC to replace the VR marker with a red marker.	The VR marker is replaced with a red marker.	1
Comments:				

Any other inputs/thoughts about the application?

Appendix B
Popular Science Summary

INSTITUTIONEN FÖR DESIGNVETENSKAP | LUNDS TEKNISKA HÖGSKOLA | PRESENTERAD 2020-11-24

EXAMENSARBETE Asymmetric Collaborative Town Development Experience using Virtual Reality
STUDENT Andy Tang
HANDLEDARE Joakim Eriksson
EXAMINATOR Mattias Wallergård

Smarta byar öppnar upp nya möjligheter för bybor att få mer inflytande

POPULÄRVETENSKAPLIG SAMMANFATTNING **Andy Tang**

Hade du velat gå hela vägen till stadshuset för att interagera med en interaktiv plattform där du kan göra allt från att kommunicera med kommunen till att få en överblick över staden? Hade du velat gå om plattformen var integrerad med Virtual Reality?

Bybor som bor i småstäder som ingår i en större kommun kan ibland känna sig förbisedda eftersom de känner att de har mindre inflytande. Detta kan dock ändras. Snabbt växande teknologiska möjligheter kan nyttjas för att integrera städer och hem med teknik, ingående i det så kallade *Internet of Things*. Med detta i åtanke kan en möjlig lösning för att öka inflytandet vara att införa en digitaliserad plattform där invånarna kan utföra specifika uppgifter utefter deras ändamål. Plattformen utvidgas sedan med Virtual Reality för att utforska och besvara huvudsyftet med arbetet, det vill säga nyttan i att arbeta i en asymmetrisk samarbetsmiljö[1].

I detta examensarbete utvecklades en digitaliserad plattform som kan användas för att öka invånarnas inflytande över byn. Byborna kan med hjälp av plattformen felrapportera, ge förslag, och visa information om byn. Arbetet fortsätter med att utforska användbarheten med att arbeta i en asymmetrisk samarbetsmiljö, och detta med hjälp av Virtual Reality. Flera användare kan då interagera med plattformen asymmetriskt, där den ena använder Virtual Reality och den andra interagerar med en pekskärm.

Arbetet testades genom att konstruera användartester där deltagarna fick besvara några inledande frågor och därefter testa plattformen på både pekskärmen och Virtual Reality. Slutligen fick deltagarna besvara avslutande frågor om upplevelsen.

De erhållna uppgifterna från forskningen visade att asymmetriskt samarbete mellan VR och en pekskärm är ett endast måttligt användbart koncept, eftersom användbarheten inte var uppenbar i en stadsplaneringsplattform. Däremot mottogs konceptet väl av användarna. Potentialen skulle ökat enormt om plattformen enbart utvecklats med hänsyn för en asymmetrisk samarbetsmiljö.

[1] Med asymmetrisk samarbetsmiljö menar man att olika användare interagerar med olika gränssnitt på samma plattform.