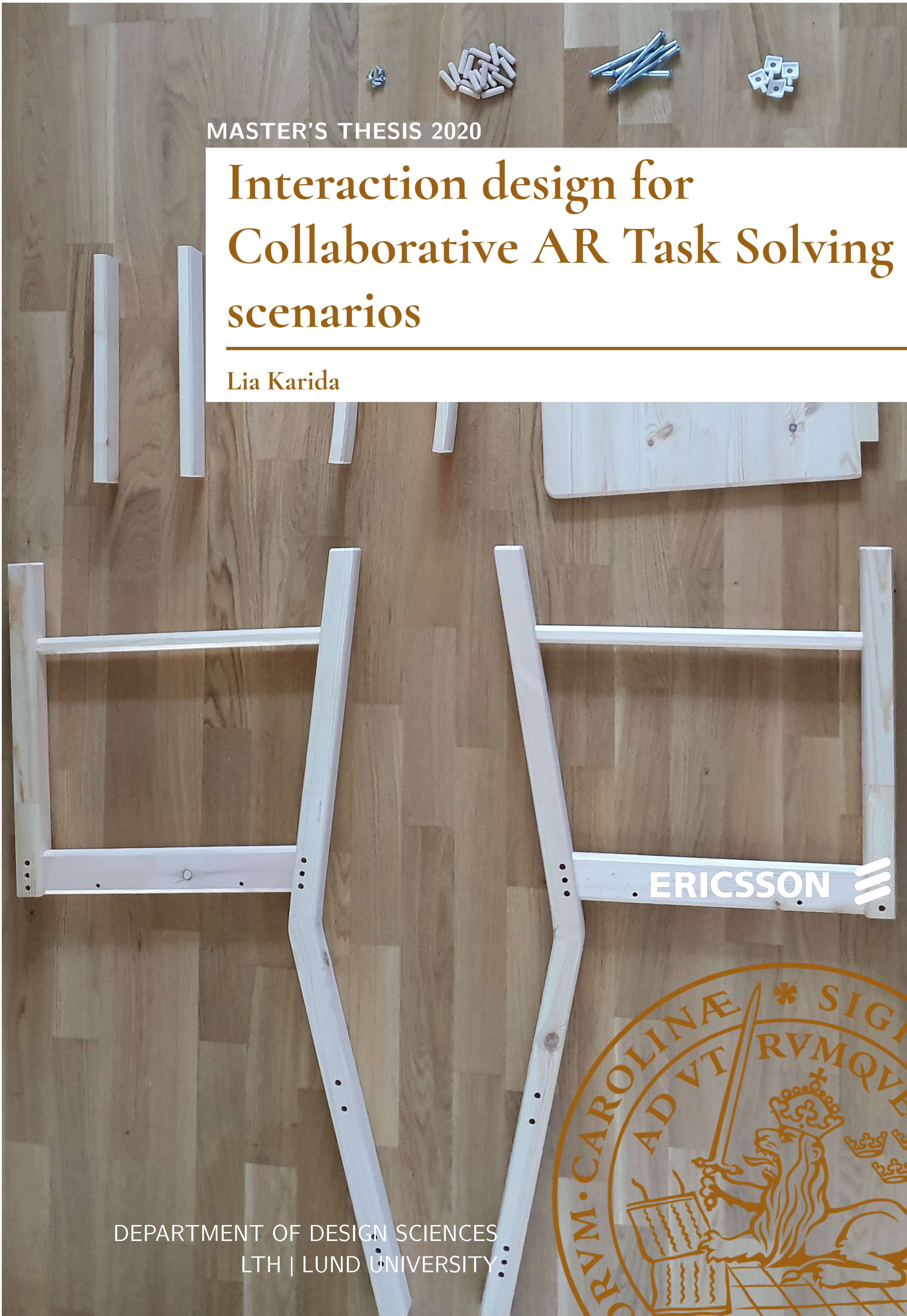

MASTER'S THESIS 2020

Interaction design for Collaborative AR Task Solving scenarios

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EXAMENSARBETE
Designvetenskaper

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Abstract

The technological combination between the real world and virtual elements is called *Augmented Reality (AR)*. The AR technology has been existing for decades, but the advancements the past years have been even more promising. There is still a lot to investigate when it comes to how to interact with AR environments through a user-centered perspective. The goal of this project has been to explore how AR could assist and facilitate collaboration between users in a furniture assembly task.

In this thesis, a conceptual development of a novel interaction technique to support collaboration in an AR environment is presented.

The project was divided into four phases and the methodology used was *iterative human- centered design*.

The (1) first phase was about choosing a scenario, which in this thesis project was *furniture assembly*, and to gather data about the target audience. An online survey was conducted which generated data from 185 respondents. The (2) second phase was to explore how the user could communicate with the system and therefore five different interaction modalities were tested by three test pairs using a Lo-fi prototype developed mainly of cardboard and paper. The aim with the (3) third phase was to study how two people collaborate with each other with assistance from the system. A focus group discussion was held and resulted in a Mid-fi prototype with sketches. The (4) fourth phase was to create a Hi-fi prototype in AR. The prototype was developed in Unity and was an AR experience of an assembly task with virtual step-by-step instructions. The fourth phase also contained to evaluate the AR assembly experience through a usability test. Five pairs of users tested the prototype and were asked to rate the usability of the system. The mean rating from the users was *Good* which is the second highest level.

Keywords: Augmented reality, Collaboration, Usability, Iterative design process, Interaction design

Sammanfattning

Den teknologiska kombinationen mellan den verkliga världen och virtuella element kallas för *Augmented Reality (AR)*. AR-tekniken har funnits i decennier men med de senaste årens framgång inom området, ser framtiden lovande ut. Det finns fortfarande en hel del att undersöka när det kommer till hur man interagerar med AR-miljöer ur ett användarcentrerat perspektiv. Målet med detta projekt var att utforska hur AR kan assistera och förenkla samarbeten mellan användare i möbelmonteringsuppgifter.

I detta examensarbete genomfördes en konceptuell utveckling av en ny interaktionsteknik för att stödja samarbeten i en AR-miljö.

Examensarbetet delades in i fyra faser och den använda arbetsmetoden var *iterativ användarcentrerad designprocess*.

Den (1) första fasen handlade om att välja ett scenario som i detta examensarbete var *möbelmontering* samt att samla in data om målgruppen. Ett online formulär skapades och genererade data från 185 respondenter. Den andra fasen (2) gick ut på att undersöka hur användaren skulle kunna kommunicera med systemet. Fem olika interaktionsmodaliteter testades av tre testpar genom att använda en Lo-fi-prototyp som var skapad främst av kartong och papper. Syftet med (3) tredje fasen var att studera hur två personer samarbetar med varandra med hjälp av systemet. En fokusgruppsdiskussion hölls och som resulterade i en Mid-fi-prototyp gjort av skisser. I (4) fjärde fasen skapades en Hi-fi-prototyp i AR. Prototypen var utvecklad i Unity och var en AR-monteringsupplevelse med virtuella instruktioner. Fjärde fasen innebar också att utvärdera AR-monteringsupplevelsen genom användbarhetstester. Fem par testade prototypen och som sedan fick betygsätta användbarheten för systemet. Testanvändarna gav prototypen medelbetyget *Bra*, vilket är det näst högsta betygsnivån.

Nyckelord: Augmented reality, Samarbete, Användbarhet, Iterativ designprocess, Interaktionsdesign

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To begin with, I would like to send a cyber-hug to everyone affected by COVID-19.

I would like to thank Ericsson for hosting my thesis work. It has been challenging in a positive way with many interesting and sometimes nerdy discussions. I would also like to thank all colleagues from the department who participated and contributed in my thesis project.

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I am very grateful for all my closest friends and family who attended as participants during the usability tests.

Lund, April 2020
Lia Karida

Contents

List of Acronyms & Abbreviations

2D two-dimensional.

3D three-dimensional.

AR augumented reality.

AV augumented virtuality.

HCD human-centered design.

Hi-fi high-fidelity.

HMD head-mounted display.

Lo-fi low-fidelity.

Mid-fi mixed-fidelity.

MR mixed reality.

MRTK mixed reality toolkit.

SDK software development kit.

SLN solution.

SUS system usability scale.

UWP universal windows platform.

UX user experience.

VR virtual reality.

XR extended reality.

Chapter 1
Introduction and the Scope

The time is 18:07, you and your partner have just returned home from the furniture store. You have recently moved together and therefore bought a new table and two chairs to the kitchen. You want to start directly by assembling the furniture, but are interrupted by the assistant in the AR glasses. The assistant gives you a notification to take a break and eat a meal first. According to the system's calculations, both you and your partner are tired after carrying the cardboard boxes and need to relax and reload the energy. After eating two sandwiches, the AR system suggests you to start by assembling the kitchen chair...

The described scenario could be a accurate in the future when AR is part of our everyday lives. It might not be a pair of AR glasses, although there are companies such as Microsoft and Magic Leap who develop this type of glasses. At the time of writing, there are also rumors that Apple is developing a pair of XR glasses and AR glasses [16]. However, in the future it could be a pair of AR lenses instead or perhaps a Brain-computer interface projecting virtual images and audio directly into our brain?

The decade for AR may be here now. Mark Zuckerberg mentioned in his Facebook post in the beginning of this year: "we will get breakthrough augmented reality glasses that will redefine our relationship with technology" [17].

1.1 Introduction

The technological combination between the real world with virtual elements is called *Augmented reality* (AR). AR can be interactive in real time and registered in 3D [2]. The AR technology has been existing for decades, but the advancements the past years have been even more promising [19]. One of the most famous games which are using AR technology is the mobile application Pokémon Go [27]. But AR has more potential than today's usage.

The Device Platform Research unit at Ericsson Research in Lund is working with device technology research regarding AR and VR. The team has a project where the main focus is to further develop function environment. Ericsson is developing knowledge and technology towards a use case in which two or more people to successfully collaborate on the same task synchronously with each other.

1.2 The project's goal & research questions

The goal of the project was to explore how AR could assist and facilitate a collaboration between users. The idea was to explore different interaction modalities for a specific task, investigate how people collaborate in AR but also develop and evaluate a solution with AR.

The main research question of the project was:

> *How and in what way could AR and interaction design be useful for people collaborating with each other over a task?*

Further, some additional questions were formulated to facilitate the research of the AR experience. These sub-questions were:

- *What AR and interaction objects are of interest?*
- *Which information and feedback are needed during the task? And is it presented differently depending on the user?*
- *Does the solution provide different assistance for the people collaborating?*

1.3 The project's scope

The purpose of the master thesis was to study the interaction between the people collaborating on a task with each other in an AR environment. The goal was very broadly formulated, but as the project progressed, the scope was narrowed down. With the help of research and various design methods, the scenario furniture assembly was chosen, which limited the scope even more. The scenario was also limited to collaboration in the same room.

The scope of the thesis included a developed solution of how to present step-by-step instructions for the users wearing a head mounted AR device. This was done by illustrations, prototypes, testing and evaluation.

Chapter 2

Theoretical overview & Related work

In order to have an understanding and a basis for the thesis project, this chapter will summarize relevant theoretical background information.

2.1 Reality–virtuality continuum & AR

Virtual continuum is a scale ranging between the completely virtual and completely real. *Reality–virtuality continuum* encompasses all possible variations of virtual and real objects, see figure 2.1 [40].

Figure 2.1: The reality–virtuality continuum [40]

- **Mixed reality, MR:** The area between the two extremes, the virtuality and the real, where these two are mixed in an experience is called *MR* [40]. MR is a merge of real and virtual worlds but is also referred to as hybrid reality [29].

  As seen in figure 2.1, MR consists both *Augmented reality, AR* where the virtual augments the real world and *Augmented virtuality, AV* augments the opposite [40].

- **Augmented reality, AR:** In AR the user can see the real world with overlayed virtual elements. AR augment the reality which means that AR supplements reality [2].

According to some researches, a head-mounted display is required if it should be called AR. Azuma [2], on the other hand, has defined three characteristics to avoid limiting AR and these are:

1. *Mixing the real world with virtual objects*
2. *Interactivity in real-time*
3. *3D registration*

- **Virtual reality, VR:** VR is a technology where the user has completely immersive experience and the experience is inside a computer-simulated reality [2].

In addition to these, there is then also the concept **Extended reality, XR**. XR is a term collecting VR, AR and MR under one word. It refers to all "real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables" [29].

2.1.1 Application areas for AR

During the past 40 years, AR and MR has had different shapes depending on the application area of use. AR has mainly been driven by *military* applications but during the last few years also by *enterprise and industrial* application. Today, the adoption of AR in the consumer and enterprise/industrial market has still not been large, despite the amount developments in AR the recent years.

Figure 2.2: An example on how AR could assist during maintenance and repair [15].

Maintenance and repair and *medicine*, are two examples of other applications areas [2]. AR instructions might facilitate the understanding if they were dawned in 3D and superimposed upon the equipment in the real world. In that way the instruction could show step-by-step tasks. Within the medicine area, AR could be helpful for medical visualization tasks in the surgical room, but it could also be useful for training purposes.

2.2 Collaboration in AR

AR can be used to create collaborative experiences where a co-located user could for example see shared 3D virtual objects which both could interact with. Another example is collaboration at a distance where a user could annotate a live video of a remote worker [14].

During the years several interesting studies has been exploring the effectiveness of using AR for complex tasks [14]. For example, Baird and Barfield [3] presented that AR could improve the effectiveness of assembly tasks for individual users while Tang et al. [35] showed that in assembly tasks, AR could improve the performance and reduce the mental effort.

There are also several researches where AR supports face-to-face collaboration, but most of the studies found online are more than 10 years old which might not make them the most accurate. They have taught the world some key lessons instead. For example, users can today interact within a shared AR experience. AR technology increases the *social presence*, the degree to which a person is perceived as "real and present" [42], compared to other technologies. Regarding remote collaboration [14], AR allows a natural interaction in the local user's physical environment [4].

In later days, the professor Mark Billinghurst pops up when searching online on "collaboration" and "AR". He is professor both at the University of South Australia in Adelaide, Australia and at the University of Auckland, New Zealand. His expertise is within human-computer interface technology with focus in AR [10]. However, many of the researches and projects he is participating in are mainly within *remote collaboration*.

In an AR/VR conference, Mark Billinghurst talked about some limitations in remote collaboration. Lack of *spatial awareness* and *situational awareness* were two examples of limitations. He presented the next generation's three ways to collaborate in MR: (1) *Sharing attention*, (2) *Sharing views* and (3) *Sharing spaces*. During his talk, different research studies from his lab [10] within MR, AR and remote collaboration was presented. He talked about *Empathic Tele-Existence* which is about to enable to feel that you are in a remote place. In that way, it is possible to be in someone else's body and know what they are seeing and feeling, but most importantly be able to help performing a task remotely.

Chapter 3
Human-centered design process

The Human-centered design process, also known as the international standard ISO 9241-210:2010, is an iterative design process where multiple of cycles of the same process is worked through. In the old version, ISO 13407, the design process has four central activities through the development [32]:

1. To understand and specify the context of use.
2. To specify the user and organizational requirements.
3. To produce design solutions.
4. To evaluate designs against requirements.

According to Don Norman, HCD is all about to solve the right problem by ensuring that people's needs are met, that the resulting product is understandable and usable for the desired tasks and that the experience of use is enjoyable [28]. With other words, HCD is a procedure for addressing these requirements. There are different variants of methods, but Don Norman defines four iterations stages (figure 3.1): (1) *observation*, (2) *idea generation*, (3) *prototyping* and (4) *testing* [28]. From the earliest stage of the project to the completion of the project, the activities should iterate until the project meets its requirements. This means that these four stages "are repeated over and over, with each cycle yielding more insights and getting closer to the desired solution" [28].

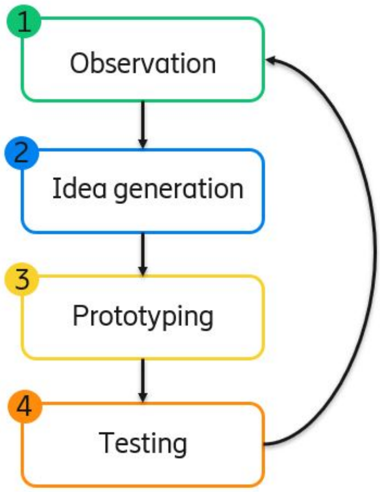


Figure 3.1: A model of HCD process.

3.1 Observation

The first stage of the HCD process is to observe the user who will use the product, attempting to understand the user's interests, motives and needs. This phase is the initial research to understand the nature of the problem [28]. It is also about to understand the user in general, their ethnography.

There are several ways to observe the users. The different methods and techniques used in this thesis are described below:

- **Focus group**
  A focus group is led by a facilitator and normally 3 to 10 people are involved in the discussions. The participants are selected to provide a representative sample of the target group. The benefit of a focus group is to arise diverse or sensitive issues that might otherwise be missed. The facilitator's role is to guide and prompt discussions. It is also up to the facilitator to encourage quiet people to participate and stop the ones who are dominating the discussion [32, p. 302].

- **Observations**
  During any stage of product development, observation is a useful data gathering technique. For example, in the design phase, observations help designers to understand the users' context, tasks and goals. Users can be observed as they perform their activities through indirectly records of the activity, direct observation in the field or in a controlled environment. This kind of technique facilitate the user/users to perform an activity or achieve a task without explaining or describing how and what they did [32, p. 321].

- **Online survey**
  Questionnaires is a technique for collecting quantitative data as demographic data and users' opinions. A well-designed questionnaire is good at getting answers to specific questions from a large group of people, depending on the questionnaire's context,

target audience and data gathering goal. Online questionnaires are a more common way of creating questionnaires. They are cost-effective and effective for reaching large numbers of people quickly and easily. [32, p. 317] Online surveys also generates faster response and automatic transfer of responses into a database for analysis [1]. In that way it is possible discover trends and patterns that can support theories and arguments.

3.2 Idea generation

Once the design requirements are determined, the second stage in the design process is to generate potential solutions. There are different ways of generating ideas. In this project, the used methods are *brainstorming* (both individual and with experts), *bodystorming* and *workshops*.

- **Brainstorming**
  Brainstorming is a generic technique used to generate, refine, and develop ideas [32, p. 503]. With this method usually two major rules are followed: (1) *generate numerous ideas* and (2) *be creative without regard for constraints* by avoiding criticizing ideas or premature dismissal of ideas. According to Don Norman there is a third rule: (3) *question everything* which encourages to ask "stupid" questions to question what might otherwise be obvious [28].

  Brainstorming has been used multiple times during the thesis work, both individual and with a expert panel at Ericsson. This technique has also been used in focus group and workshop sessions.

- **Bodystorming**
  Bodystorming, also referred as "embodied storming", is often considered a form of prototyping in context, and is enacted instead as a technology directly supporting collaborative embodied cognition [31]. This technique departs from ideational methods. Embodied storming can be applied as a design-research method, to help identify gaps and opportunities.

  In this project, the used type of bodystorming can be called "use-case-theater", which means that the users where physically interacting/exploring the system to generate new ideas.

- **Design thinking workshop**
  Design thinking is all about the importance of developing products that fit the users' desires, needs and capabilities. With other words, the fundamental issue needs to be addressed [28]. In this thesis a design thinking workshop means it is a hands-on, activity-based session [33]. The idea is through collaboration and problem-solving build empathy for the target users, generate ideas and in some cases also build a Lo-fi prototype.

  In this thesis, this kind of workshop was performed together with an expert panel at Ericsson.

3.3 Prototyping

Prototyping is the stage during the iterative design process where the ideas from the previous step, idea generation, are prototyped and later tested. This to see if the ideas are reasonable or not [28].

In this thesis, the prototyping is divided into three phases: (1) *Lo-fi*, (2) *Mid-fi* and (3) *Hi-fi*.

- **Lo-fi prototyping**
  Low-fidelity, Lo-fi, prototypes tend to be simple, cheap and quick to produce and modify. Usually made of paper and cardboard and is not intended to be integrated into the final product. This type of prototype is important in early stages of development to explore alternative designs and ideas [32].

  There are different ways of Lo-fi prototyping, in this thesis prototypes in cardboard, sketching and Wizard of Oz was used.

  - **Wizard of Oz**
    This is a prototype technique which is usually used during tests. Wizard of Oz allows an interaction between a user and an interface/a system, where the responses are generated by a human rather than a computer. It is a cost- and time-effective way to try design concepts without having to think about the development.

    During both Lo-fi testing and Hi-fi testing, the technique Wizard of Oz was used to activate some functionalities which were not implemented or because of technologically constraints.

- **Mid-fi prototyping**
  Mid-fi is a new terminology used within prototyping in interaction design and means *Mixed-fidelity*. It is used as a stage between Lo-fi and Hi-fi. With other words, the prototype consists "High-fidelity on some dimensions and Low-fidelity on others" [18].

  A combination of functionalities from Microsoft's online tutorials on HoloLens 1 and own sketching was provided in this thesis.

- **Hi-fi prototyping**
  A *High-fidelity*, Hi-fi, prototype takes longer time to build/produce and is more expensive. Usually this kind of prototype uses materials that would be expected in the final product, for example a software product will probably be prototyped in a software tool. [32]

  In this project will a Hi-fi prototype be implemented in Unity with Vuforia and Mixed Reality Toolkit.

3.4 Testing

In HCD, the *iterations* are very important since they enable continual refinement and enhancement. The aim is rapid prototyping and testing. With each cycle of iteration, tests and observations gets more targeted. Testing is the last stage in the design process. Feedback on the prototype is a critical part of the design development. This thesis contains tests after each prototyping iteration, both *explorative testing* and *usability testing* are used.

- **Explorative testing**
  This is a method of testing as "thinking", which means that the product/system gets tested while trying it out without any test cases created in advance.

  The first iteration of the Lo-fi prototype was tested exploratively in combination with bodystorming.

- **Usability testing**
  The point with usability testing is to test whether the developed product is usable by the target audience to achieve the tasks for which it was designed [9]. It is the product that is being tested and not the user. Data is collected, often is different combination of methods used for this. Specific parameters are collected during the user test. An acceptable number to test is considered to 5-12 users [9] or fewer, it depends on the budget and schedule constraints.

  The Hi-fi prototype was tested by a usability test. After the test, the test persons filled in a questionnaire contained both demographic questions and a satisfaction survey.

  - **System Usability Scale, SUS**
    SUS is usually used as a user satisfaction survey and was invented by John Brooke in 1986. It is a tool to quickly and easily collecting a user's subjective rating of a system's usability. SUS is a *Likert scale* with ten questions where the user rank each question from 1 (Disagreement) to 5 (Agreement) [6].

    A usability score, called *SUS score*, can then be calculated. Every other question is asked positively, and every other negative. For each of the odd numbered questions, subtract 1 from the score and for each of the even numbered questions, subtract their value from 5. Then summarize the new values and multiply it with 2.5. The score should have a range of 0 to 100 [6].

    Figure 3.2 shows that the average SUS score is 68. If the score is under 68, then the usability of the system is considered as bad. A score higher than 80.3 is an A [6].

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 3.2: General guideline on SUS score interpretation [30].

Chapter 4
Collaborative Task solving scenario

In accordance with the Cambridge Dictionary, a *collaboration* is "the situation of two or more people working together to create or achieve the same thing" [8]. This can be done and fulfilled in many different types of situations. To facilitate the research and the prototyping in this thesis, one specific scenario was chosen. The following design decision in the thesis was adapted to the scenario but could be applicable in several areas in the future.

A focus group was first formed to give insights about important factors of collaboration and to come up with ideas of potential scenarios that could be used in the thesis. Four ideas followed from the focus group to the next step that was a design thinking workshop. The workshop then ended in a new brainstorming session were a specific scenario was chosen.

4.1 Focus group about collaboration and AR

A focus group of five people was convened. The participants were all in different ages. Two (n=2) of the participant were males and three were females.

Each participant was given post it-notes to write down their thoughts on. They were asked to write only one word on each note. The whole session took about two hours and was audio recorded.

The idea of the focus group was to discuss and explore what it means to the participants to collaborate and to brainstorm and find potential scenarios both where a virtual assistance could be integrated and situations where a virtual assistance could be needed.

The participants started to reflect on the meaning of *collaboration* and wrote down qualities, characteristics, feelings, tasks etc. they associated with the term. Afterwards each participant presented their notes and then they categorized similar post it-notes together to a list where the most important association was at first place. Further, the participants were commissioned to first describe their latest situation where they needed to collaborate with two or more people, and later brainstorm how a virtual assistance could be integrated in the scenario.

Table 4.1: The four ideas from the focus group session are described and how to integrate AR in the collaboration.

THE FOUR IDEAS			
Nbr	**Scenario name**	**Description of the collaboration**	**How to integrate AR**
1	Furniture assembly	When you buy a piece of furniture these days, you need to assemble it yourself or together with someone. You receive often instructions which guides you through the process.	AR could assist during the whole or part of the assembly process. The instructions could be in AR.
2	Cooking	Cooking is part of our everyday lives, but it is more fun to do it with someone else. It is also a social interaction.	The recipe could be in AR and the AR could also assist in keeping track of all steps.
3	Video conference	There are many workplaces that have video conferencing. It is a convenient way to attend a meeting that you cannot physically attend to due to various reasons. Usually a presentation is shown during the meeting.	If every participant instead wears a pair of AR-glasses, the presentation could be represented with holograms etc. Modifications of charts and statistics could be changed in real time. Also, a holographic representation of the non-present person could be available.
4	Party preparations	When planning and preparing a party, good communication and clear responsibilities between the responsible parties are required.	AR could assist in the schedule planning for each person. If one person is in town to buy the last missing things, a remote collaboration could be useful to facilitate the communication.

4.1.1 The result from the focus group

The participants came up with a lot of different ideas where there is a need of collaboration. In school, at work, at home, during travels, in relationships, in sports were some examples on environments that were discussed. There were also discussions about collaboration in a bigger scale as in politics, both nationally and internationally.

During the discussions, the focus group came up with a lot of ideas where collaboration was in focus. The focus group agreed on four of the ideas where an integrated AR assistance would improve the collaboration. The four ideas are presented in table 4.1. Two of the ideas, *Video conference* and *Party preparations*, included remote collaboration.

4.2 Design thinking workshop

To continue with the result from the focus group, a workshop was held. In the workshop, four participants were invited: two people from Ericsson in Lund and two people were remotely present from Ericsson in Kista. Three of the participants were males and one was female.

The workshop was divided into three parts where the first part was an introduction to the thesis project and its research questions. The first part included also that each one briefly presented themselves and shared their design experience. The second part was about presenting the four ideas from the focus group. This was done by showing a *mood board* for each idea that had been created in advance. The mood board was used as a presentation tool to give a visual insight of the overall idea with images, colors and text in a composition. The third part was about to discuss each of the ideas and brainstorm on how AR could be integrated. Both previously known research in the various areas and which scenario best fitted to the thesis project, was discussed. The result of the workshop concluded with excluding the two remote collaboration ideas. The reason to this was because the thesis project's scope was to investigate the collaboration "in the same room".

4.3 Brainstorming session & the scenario

A new brainstorming session was called but this time only the two onsite participants, from the design thinking workshop, participated. A list of pros and cons was created during the session. The list included everything from the idea's area of use to previous related researches within the idea's area. During the session, how to do the prototype development for each of the ideas was discussed but also what kind of technologies would be required. Different ways of collaboration were also discussed during this session. It was stated that there are different types of collaborations and that it is relevant to research on the different kinds. Since this thesis project is focusing on collaboration, the chosen idea (scenario) should give rise to collaboration between two persons.

Based on the result and the discussions during the session, a comparison between the two ideas of scenarios was conducted. The chosen idea, which from now on will be called *scenario*, was *furniture assembly*. The two main reasons for the decision were: (1) there is a greater collaborative interaction between two persons when assembling (depending on the furniture), in compare to cooking, and (2) there are more research materials and related work within furniture assembling.

Chapter 5
Data gathering

The collaborative task solving scenario was chosen and the scope was now concretized. The first stage of the HCD process is *observation* which means that a research to understand the target users, is in focus. The target audience's interests, motives and needs form the basis of the product's requirements [28].

In an iterative design process, this stage is fundamental to a human-centered approach. To understand these needs, data gathering, and analysis is of importance. In this thesis project, this chapter corresponds the first stage of HCD process.

5.1 Defining the user

When working with the design process, as already mentioned, it is important to understand the users. By defining the target users for the chosen scenario, it improves the understanding of who the potential users are and what kind of support an interactive product could usefully provide. [32]

An online survey was created and sent online. Thereafter, the gathered data was analyzed and used to define the *primary users* with *personas* and *user scenarios*. An observation on collaboration during an assembling task was also observed.

5.2 Online survey

The tool used to create the online survey was Google Forms. It was later sent internally within the department at Ericsson. The survey was also posted on the social media platform "Facebook".

In this project, the responses from the online survey were used to understand the potential users by trying to primarily identify the primary users; their background information, experience in furniture assembling and how they use the instruction manual.

In total the online survey received 185 (n=185) responses. 106 (57.3%) of these defined themselves as female, 78 (42.2%) as male and only one person as other. The majority (n=94, 50.8 %) were single or in a relationship. Equal number (n=44, 23.8%) of the respondents were married or in a domestic partnership. Two respondents were widowed and only one person was divorced.

Table 5.1: A summary of the work areas among the respondents.

Work areas	Quantity
Student	88
Technology and IT	36
Education-Related	11
Healthcare	10
Manager/Director	5
Municipal official	5
Research	5
PhD	3
Education	2
Lawyer	2
Restaurant business	2
Logistics	2
Communicator	2
Other	12
Total	185

Table 5.1 shows the respondents' work area categorized. Most of the respondents were students (n=88). The work area *Other* is a collection of professions mentioned only once, some examples of these professions are cleaner, priest and film producer.

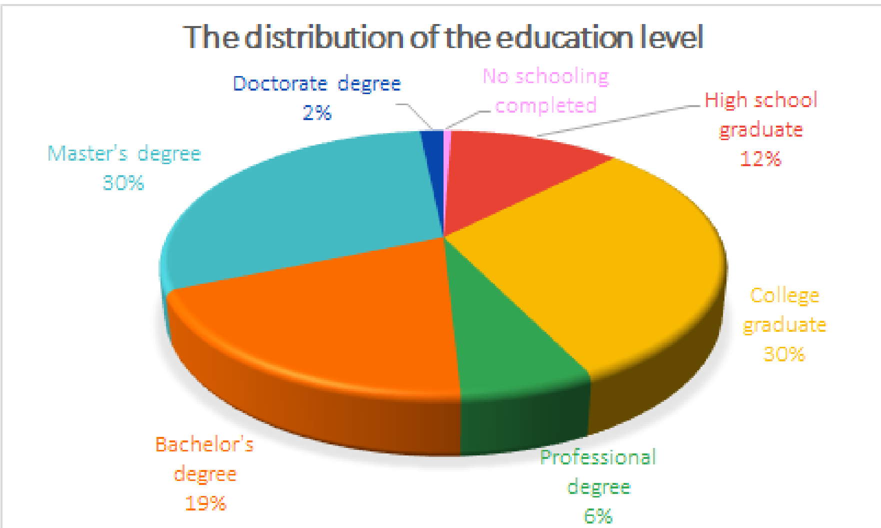


Figure 5.1: The distribution of the highest completed education level among the respondents.

Figure 5.1 shows a pie chart of the distribution of the highest completed education level. *College graduate* is the highest completed education level of the majority (n=56) of the respondents. Closely followed by *Master's degree* with 55 respondents. Three respondents has a *Doctorate degree* and only one person has no schooling completed.
Most of the respondents had an age between 15 to 34 years old. In figure 5.2, 70 respondents were between 15 and 24 years old and 64 respondents were between age 25 and 34. The lowest (n=12) age distribution was the respondents between 35 and 44 years old.

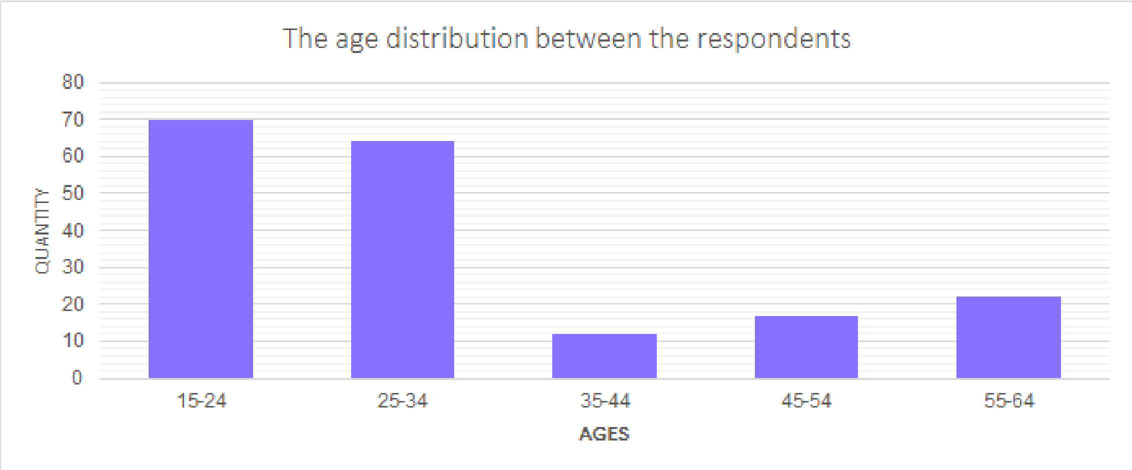


Figure 5.2: The age distribution between the respondents.

The first question regarding furniture assembling on the online survey, was if the respondent has ever assembled, alone or together with someone else, a furniture? 98.4% (n=182) of 185 respondents answered "Yes" on this. Furthermore, the remaining 182 people had to fill in on a Likert scale [32] of 1 to 4, how difficult the respondent thinks it is to assemble a furniture. 1 on the scale corresponded "Simple" and 4 "Difficult". The result can be seen in figure 5.3.

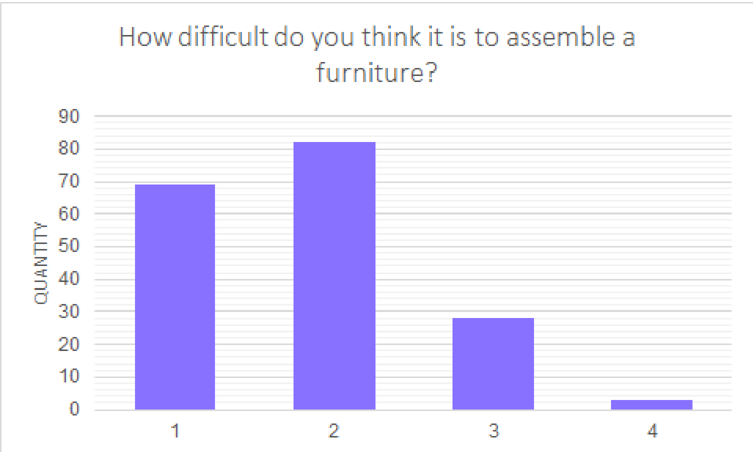


Figure 5.3: The distribution between the responses on a Likert scale, where 1 is "Simple" and 4 is "Difficult".

The same number of respondents were also asked to fill in how many times they have assembled a furniture, alone or together with someone else. The majority (n=109, 59.9%) had assembled furniture 11 or more times. 43 respondents (23.6%) had assembled furniture between six or ten times while 30 respondents (16.5%) between one to five times.

176 (96.7%) of 182 respondents answered that they are using the included instruction manual when assembling a furniture. The distribution on how difficult the respondent thinks it is to understand the instruction manual is presented in figure 5.4.

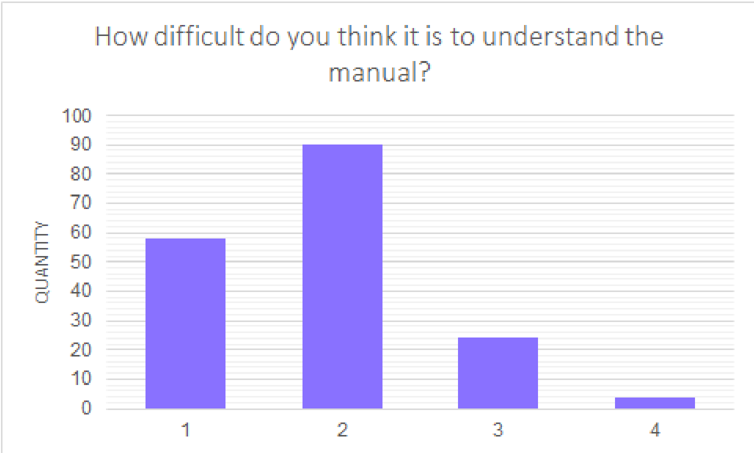


Figure 5.4: The distribution between the responses on a Likert scale, where 1 is "Simple" and 4 is "Difficult".

Figure 5.5 shows the different reasons why the respondents are using the instruction manual. The three main reasons are: (1) *to avoid mistakes*, (2) *it goes faster to assemble* and (3) *the pictures in the manual are easy to understand*.

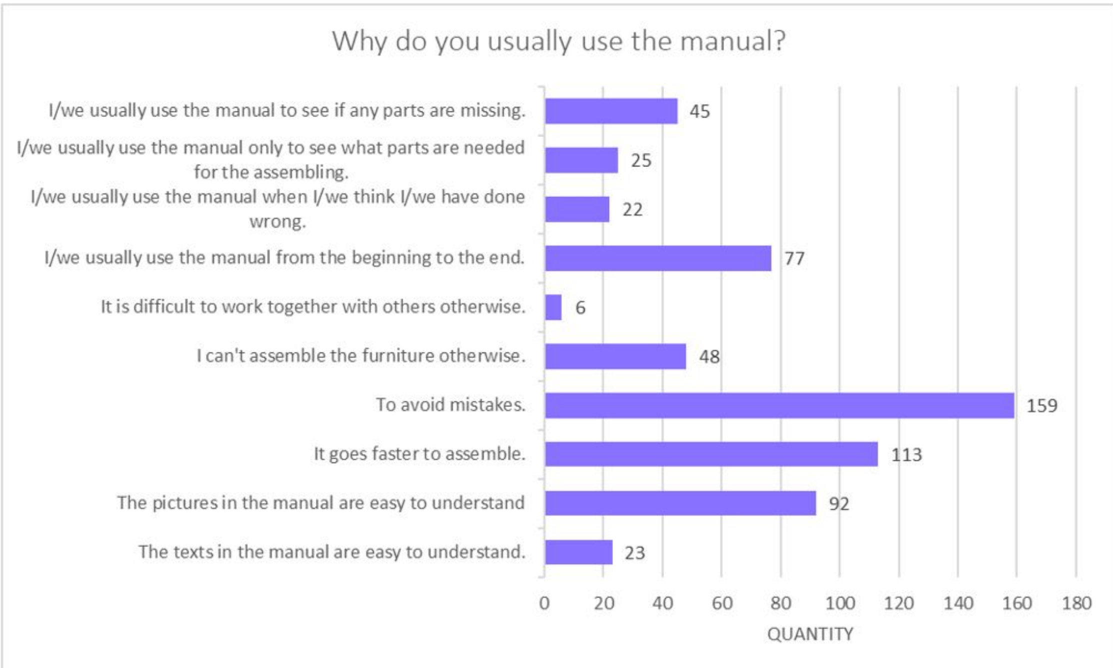


Figure 5.5: A multiple-choice question from the survey which summarizes the total number of times that each option was selected.

5.3 Personas and user scenarios

A way to collect attributes for a "typical user" and to identify the target users is by creating a *user profile*. User profiles are often transformed into *personas* [7]. Personas are fictional characters with detailed descriptions of the typical users. Personas are used as a design guideline during the design development and are usually combined with a *user scenario*.[32, p. 481] A user scenario is a fictitious story of a user's (or persona) accomplishing an action or goal via the product to be developed.

Through the online survey, several different user profiles appeared, and five personas were created together with three user scenarios. All of the personas represented the *primary users* but in different types. The primary users were those who were in direct contact with the system. They represented a large section of the intended user group - the frequent users.

Persona 1 and persona 2 were the *regular* users. Persona 3 and persona 4 were *novices*, which means that they for example needed a system with step-by-step instructions and clear information. Persona 5 represented the *expert*, who will probably require a more flexible interaction with the system [32, p. 481].

5.3.1 Persona 1

About: Sabrina is 25 years old and has a master's degree within Computer Science engineering. She works as a Software Developer at a local IT company. Sabrina has recently moved in to an apartment in town together with her boyfriend John (persona 2).

Type of user: Regular user.

Other relevant background information: Experienced (*intermediate knowledge*) furniture assembler who finds it *pretty simple* to assemble furniture. Takes assistance of the manual's *easy-to-understand images* during the whole assemble process, from the *beginning till the end*. She thinks the manual is in general *quite easy* to understand and is using it to *avoid mistakes* and to make the assembling go *faster*.

Experience goal: She wants the manual to be easy to understand.

End goal: Successfully assemble the furniture fast and without any mistakes together with John.

5.3.2 Persona 2

About: John is 24 years old and a medical student. He is in relationship with Sabrina (persona 1). They have recently moved in together to an apartment in town.

Type of user: Regular user.

Other relevant background information: Experienced (*intermediate knowledge*) furniture assembler who finds it *simple* to assemble furniture. Takes assistance of the manual's *easy-to-*

understand images. He thinks the manual is in general *quite easy* to understand and is using it to *avoid mistakes* and to make the assembling go *faster*.

Experience goal: He wants the manual to be easy to understand.

End goal: Successfully assemble the furniture fast and without any mistakes together with Sabrina.

5.3.3 User scenario 1

The clock is 18:07 and Sabrina and John have just arrived at home from the furniture store. They have recently moved together to an old apartment in the city center and needed to buy new furniture and decorations for the apartment. They bought a new glass cabinet, bookshelf, pots and colorful pillows for the living room.

After a short food break the pair decided to assemble the glass cabinet. They started with open the cardboard box and Sabrina took out the furniture manual and placed it, with the first page opened, on the floor. Both Sabrina and John started to look at the first images in the manual. Then, John grabbed the first piece which looked the same as the illustrated part in the top-left image in the manual. Sabrina continued by picking up the second piece, the supplied screwdriver and the screws that was needed for the next step. She right-placed the second part into the first one with contribution of John. Then he griped the two parts while Sabrina screwed the screws on the right place with the screwdriver.

With the assistance of the manual they continued step-by-step assembling the whole glass cabinet together. They were done after approximately 25 minutes and then took a small break before they opened the cardboard box for the book shelf.

5.3.4 Persona 3

About: Marie is 46 years old and married. She lives in a villa in the suburbs with her husband and two children: Lina, 18 years old and William, 15 years old (persona 4). Marie has a bachelor's degree in finance and works as a Personal Financial Advisor at a national bank.

Type of user: Least competent user

Other relevant background information: Has *fundamental knowledge* of assembling a furniture since she has done it *1-5 times*. *Always* takes help of the manual since she can't assemble without it, even if she thinks it is *quite difficult to understand* it. The manual is used from the *beginning of the assemble process till the end*. It is mainly used to *avoid mistakes*, but also to make the process go *faster*.

Experience goal: She wants to understand the manual.

End goal: Successfully assemble the furniture.

5.3.5 Persona 4

About: William is 15 years old. He finished the secondary school this summer and just started high school. He is taking classes in science since he has a huge interest in astrology. William is living with his family close to the high school. His mother is Marie (persona 3).

Type of user: Least competent user

Other relevant background information: He is *novice* since he has *never* assembling a furniture before.

Experience goal: He wants to learn how to assemble furniture.

End goal: Help to build the furniture.

5.3.6 User scenario 2

William is not a child anymore. He has begun high school and want to change his room. He thinks the room is very childish and wants it to fit his maturity. After an intense discussion over the dinner the other day, his parents decided to give him a small budget to fix his room.

Next day, William's mother Marie picked him up after school. They went to a furniture store and William decided to only by a new desk. When they returned home, William was eager to directly start assembling the desk. He had never done it before, so he was very excited. Marie, on the other hand, was not that happy. She had only assembled a furniture a few times and didn't felt comfortable with the whole assembling situation. William started to open the cardboard box and took out every piece on the floor. Marie grabbed the manual and started nervously to browse through it. She had a hard time understanding which screws were needed to put on the first piece. William took the manual from her hands and looked at the first image. Marie is stressed so she got annoyed and yelled at him. He gave her back the manual and picked up the right screws from the plastic bag on the floor and put it into the holes on the first piece. Marie double-checked if he got it right, before she started to look at the next instruction.

After approximately 1,5 hour they finished the assembling. They succeeded to assemble the desk. Every step went slowly but surely forward since Marie was followed every instruction carefully. It went a little bit slow for William but has now tried and learned how to assemble a furniture. And best of all, he has a new cool desk in his room.

5.3.7 Persona 5

About: Daniel is 29 years old and his highest education level is high school. He has for several years been working as an official of the municipality. He has for the two past years been studying at the university where he wants to become a teacher in history. He lives alone in a student apartment five minutes from the university.

Type of user: Expert user

Other relevant background information: Experienced (*advanced knowledge*) furniture assembler with skills without assistance of the manual. Finds it *simple* to assemble furniture. He either assembles the furniture *himself* or *together with someone else*. If he does it together with someone else, then the other person usually uses the manual.

Experience goal: He wants to successfully assemble it all by himself.

End goal: Assemble the furniture without the manual.

5.3.8 User scenario 3

It is Tuesday afternoon and Daniel can't concentrate on his reading for the exams next week. He feels a little bit depressed since he and his former partner Alex broke up a few days ago. He goes to the kitchen to make some coffee. On his way, he stumbles on his shoes in the hall. Daniel got frustrated that he still hadn't assembled his new modern designed shoe cabinet with four compartments. The idea was to do it as a weekend activity together with Alex, but now Daniel has to assemble it by himself. The thing is that he doesn't mind doing it alone, but he doesn't mind doing it together with someone else either. Daniel decides to assemble the furniture today since he needs a break from his reading and his own negative thoughts.

Daniel opens the cardboard box and places all the furniture's parts on the floor. He categorizes them after sizes and functionalities, e.g. all the screws are together etc. He leaves the furniture manual in the cardboard box. Daniel has built the same type of furniture once before, so he starts by picking up all the fasteners and inserts them in the holes on every furniture part. Then he use the screwdriver to attach the pieces. Daniel continues at his own pace and successfully assembles the furniture.

Afterwards, when he compared to the instruction manual, Daniel deviated from the assembly order in the manual. But it didn't matter because it went well anyway.

5.4 Observation on a collaborative assembly task

To support the online survey of the user group, a qualitative observation was done. The aim of the observation was to get an idea of how people during an assembling task, collaborate with each other with or without an instruction manual.

The assembling task was to assemble a Lego helicopter, see figure 5.6. All the Lego pieces and the instruction manual was inside a box and the only task instruction the participants received was to assemble the Lego helicopter together.

The factors that were observed were if (1) *the participants successfully finished the task* and if (2) *the instruction manual was used during the task.* If the answer on the second observation question was positive, then a third factor was observed: (3) *how and in what way* was the instruction manual used.

Figure 5.6: The Lego helicopter construction [13]

5.4.1 Notes from the observation

The participants were female. One were 16 years old, referred to P1, and the other 20 years old, referred to P2. Both of them had assembled Lego several times before, but it was a long time ago. When they assembled, it was not a specific motive as in this case a helicopter.

The participants started by pouring out the Lego pieces. Both participants wanted to use the instruction manual from the beginning. P1 started by collecting all the pieces that had the same color in piles. She continued to pair similar pieces within the same color. Meanwhile, P2 was looking in the instruction manual. Afterwards, P2 read the first instruction from the manual and P1 put together the pieces. This was repeated throughout the task.

When P1 assembled a piece wrong, P2 corrected her orally and when P1 couldn't find a specific piece that was requested, P2 pedagogically described the piece. If P1 felt insecure where exactly to place a piece, she asked P2.

Sometimes when P2 took too long to read the instruction, P1 started by her own using her imagination, to assemble next step. One example was when it was time to assemble the piece of the helicopter's propeller. There were two possible places to attach the piece with the propeller and P1 picked the wrong place. P2 did not detect the error since she assumed that it was "obvious" where the Lego piece would be placed. P2 detected the misplaced piece during the next step because the new piece were supposed to be placed where the propeller was.

When there were two identical Lego pieces that would be mirror-mounted on the construction, each participant took a piece and put on. P1 missed once when P2 had mounted on one Lego piece and then P1 asked her to re-do it.

Chapter 6
Lo-fi development

From the personas and the observation, it turned out that the interaction for a collaborative task depended on different interaction aspects. All points of view are of interest in this project, since the idea is to investigate interaction design possibilities in collaborative AR. The aspects are divided into three phases:

1. The interaction modalities between the user and the system.
2. The interaction between the users.
3. The visual interaction and feedback in AR (includes holographic data and feedback).

All three phases were considered as important in the following prototype development. It is also relevant to keep in mind that these three phases were all explored in an AR environment.

6.1 Lo-fi prototype

A Lo-fi prototype was developed mainly through cardboard and paper. The same Lego construction from the observation was used in the Lo-fi prototype but also during the Lo-fi tests.

Firstly, the manual for one of the models (the helicopter construction) was copied, cut out and pasted on small pieces of cardboard. Afterwards, they were numbered in correct assembly order. A check mark, a cross, two arrows and a progress bar with ten small rectangles was also cut out in cardboard. The bock was colored in green, the cross in red, one arrow in pink, the other arrow in yellow and the small rectangles in blue. Figure 6.1 shows the Lo-fi prototype and all the different parts used in the Lo-fi tests. To this, two pair of glasses of pipe cleanser were formed.

The main purpose of the Lo-fi prototype was to explore the first åhase - how each user is interacting with the system and the instructions. The idea was to investigate which of the interaction modalities in AR were most suitable for the collaborative assembly scenario.

Figure 6.1: The Lo-Fi prototype.

Another interesting point from the tests was also to receive ideas on relevant feedback which is connected to the user interaction with and between the users and the system.

During an individual brainstorming sessions, five modalities were derived:

1. Hand gesture
2. Voice command
3. Automatically (gaze and dwell)
4. "Stare" (eye tracking)
5. Point

The modalities were tried out during the Lo-fi testing. The first (1) modality was *hand gesture*. The test persons was supposed to do a "swipe" gesture in the air to receive the next instruction. The second (2) modality was *voice command* where the test persons needed to say "Next" to continue to the next instruction. The third (3) interaction way was about the system *automatically* (called gaze and dwell) to give the next instruction when the previous step was defined as done (all pieces were placed correctly). Fourth (4) interaction modality was about to stare on the construction, in the Lo-fi tests it was about two seconds before next instructions was given. The fifth (5), which also was the last modality that was tried out, was to *point* on virtual arrows to get the next assembly instruction.

6.2 Lo-fi testing

The Lo-fi tests were performed in three rounds, in every round the test was tried out in pairs of two. In total, it was six (n=6) test persons, five people from the research department at Ericsson and one professor from LTH. The test persons were classified as AR-experts since they have experience of AR and/or are working on a daily basis with similar technology. During the testing, notes were made by hand. The Lo-fi testing took about one hour: 5 minutes introduction, 40 minutes execution and 15 minutes post-test interview.

6.2.1 Explorative testing

The used method during the Lo-fi tests where a combination of explorative testing, bodystorming and Wizard of Oz technique. The participants were instructed to use the *think-aloud technique* which is a useful method to understand what is going on in a test person's head [32, p. 336].

The Lo-fi test begun with each test person put on the fictitious AR glasses made of pipe cleanser. All the cardboard pieces represented a hologram. If the test person took off the glasses, the holograms were not visible.

Figure 6.2: One of the test pairs during the Lo-fi testing.

On the table in front of the test persons, the Lego box was placed. They opened the box and poured out all the pieces on the table. Then they received, through Wizard of Oz, the first hologram from the system. The hologram was a miniature of the final construction, in this case the helicopter in Lego. The test person had the opportunity to manipulate and move the miniature hologram if desired. The first step of the assembly task was showed as a new hologram and contained the current pieces to be used during the first step. The arrows showed which pieces and how many of them should be picked up. When the piece was picked up, the arrow disappeared. A new hologram was revealed when all pieces in the current step was picked up, see figure 6.2. The hologram contained an image on how the pieces should be assembled. The test persons were asked to imagine the pieces in the hologram image was animated. If the assembly was correct, the green check mark appeared and one of the blue rectangles was placed on the progress bar. This was repeated but after about 3-4 steps the interaction modality changed to the next until all five different modalities were tried out. In the case when the wrong piece was picked up or the assembly was incorrect, the red cross appeared.

All pairs completed the tasks successfully. New insights and feedback were written down during the tests. The result of the tests were a combination of the notes and the discussions from the interviews in next section.

6.2.2 Post-test interviews

After each Lo-fi test, the pairs had a *semi-structured* post-interview. A semi-structured interview has a basic script for guidance and open-ended questions, allowing for a discussion.

Two of the three pairs preferred the interaction modality were the system automatically understood the next step. The reason was that it was the least strenuous. It was the most intuitive alternative since the explicit feedback already informed the users if the assembly was correct or incorrect, the system should automatically continue to next step. The third pair liked the eye tracking modality. Since the users needed to look at the construction regardless, therefore it was no extra effort to stare at it a little longer. They also gave the explanation that in communication, eye tracking is a very natural part because you usually look at the person you are talking to, otherwise it can cause misunderstanding.

All three pairs thought a *multi-modal* interaction would be the most preferred alternative. Each pair had various combinations and ideas on how to combine the different modalities and in which situations what modality would be preferable. However, they were all agreed on to include voice command. Most of the participants also agreed that audio feedback would have been a good alternative in combination which the visual feedback.

Below are some interesting ideas or discussion that were said during the interviews:

- Discussion about multiple coordination: How to coordinate multiple people in a collaboration and at the same time avoiding collisions. A solution could be a master/slave relation, where the master will be able to have the control powers.
- The system could give different alternatives in different colors on how to solve the assembling, like today's navigation application where various routes are suggested.
- The progress bar was considered as a very important functionality. An idea was a possibility to ask the system "how far have I come?".
- A virtual assistant where the assistant could for example walk around on the table and show which pieces are going to be used. This idea appeared during a discussion where

a "random" voice from the system could create confusion. It gives also an unnatural feeling since the voice comes from nowhere.

- The instructions should adjust to the field of view of the users. The hologram with the instruction should be placed quite close to the person who assemble.
- Use colors to facilitate the assembly process.
- When picking up a piece, you could see where on the 3D-hologram of the final product is the piece located. Like an exploded view of the final product.
- The pieces which will be used in the current step could be visualized in AR, for example they could be highlighted or projected with a hologram of the piece above.
- The AR assistant could schedule when to assemble and give information about how much time it will take. The assistant could also calculate the users' experience skill.
- There should be a possibility to continue to next step even if the assembly on current step is incorrect.
- A possibility to make own choices, the step-by-step instructions should not be so strict.
- Next to the current step, be able to see next instruction shadowed, similar to the presentation tool Power point. This would improve the overview of the steps.
- A futuristic idea where the system could be mind-reading. Neurological sensors in the body could read and measure the situation the user is in and act thereafter.

6.3 Second iteration

The focus on the second iteration was to investigate the second phase *2. The interaction between the users*. Therefore, a focus group with the same people from the Lo-fi testing participated. The idea during this iteration was to combine the new insights from the first iteration with the results from the focus group.

After the focus group session, a Mid-fi prototype was created. It was done by drawn sketches in combination of different ideas of technology that could be applied.

6.3.1 Focus group about user interaction between users in AR

As already mentioned, the same test persons from the Lo-fi tests participated in the focus group. By inviting the same people, discussions from the tests could be reflected again but now from a new perspective. The goal of the focus group was to explore different ideas on how the interaction between people who are collaborating could look like, but also discuss how the AR assistant could improve the users experience during the collaborative task.

The focus group session took about 1.5 hour and was divided into three parts. Each section had dedicated half an hour for discussion. Every section begun with a scenario presented and was followed by a question. The scenario was the same during all three discussions, only the question was changed. The following quotation presents the scenario which was used during the session and the three questions:

> *"The clock is 18:07 and Sabrina and John have just arrived at home from the furniture store. They have recently moved together to an old apartment in the city center and needed to buy new furniture and inventory for the apartment. They bought a new glass cabinet, bookshelf, pots and colorful pillows for the living room. After a short food break the couple decided to assemble the glass cabinet."*

1. How could the AR assistant help Sabrina and John to get started? Any ideas on necessary or important functionalities that the AR assistant could provide?

2. How will the interaction between the users look like? Do they receive same instructions from the AR assistant? Or are some functionalities limited to only one user?

3. What kind of feedback is relevant for the users to receive by the system during the assembly process? Is it different depending on the instruction?

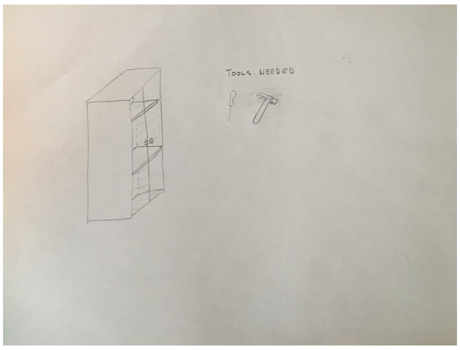
A lot of ideas where the system acts as an assistant or as a secretary was given during the first question. The focus group thought that the system should check each schedule of the people in the collaboration and suggest a time slot that fits all. The system should active consider if it is too late to assemble or give an option to re-organize the task. The system should have the ability to give different kind of instructions depending on the user's experience skill and should also be able to read the other users' mood in real time. For example, if the other person is tired the system should interrupt the task before the assembling starts. Furthermore, the participants thought the tools to be used in the construction should be shown, to give the users the opportunity to prepare themselves. Other ideas as information about how much time it will take, schedule breaks, an overview of the process and a suggested "assembling area" in the room, was also mentioned during the focus group session.

During the second question, the participants in the focus group did not agree completely. There were two different perspectives on how the collaborations between the users could be. Some of them thought the users should decide everything by themselves by dividing subtasks to each other. The other point of view was to allow the system decide everything with a possibility for the user to change their subtask. The discussion ended up in a solution where the AR system should give instructions to everyone within the task, otherwise, there is a risk for someone to feel left out. The system should not divide a task into completely individual subtasks because in that way the whole point of the collaboration is lost. The point with the AR assistant is to be a collaboration tool. Further, the system should have transparency and be able to distinguish whether the users talk among themselves or with the system in voice command.

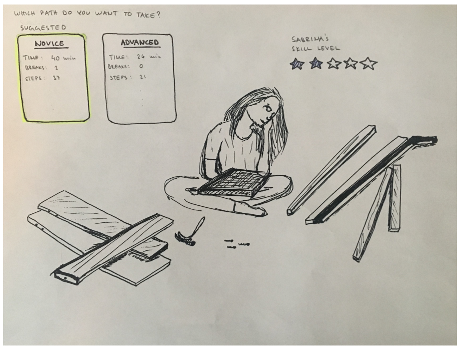
The discussion about the last question was very similar to the post-interviews from the first iteration. For example, a progress bar and highlighted pieces were of interest. The main difference between an AR instruction manual with a physical manual, is the advantage that in AR could the instruction steps be animated. Extra information about where and in which angle to hold the furniture part or how to hold the drill to not damage the surface, could also be appreciated feedback.

6.3.2 Sketches and feedback

From the focus group session, the mentioned ideas were merged with each other and combined with the Lo-fi prototype. A Mid-fi was created. The Mid-fi consisted different sketches on how the AR system could assist during an assembly scenario. Various functionalities and features from the online tutorials (see next chapter) where conceptually integrated with the ideas.



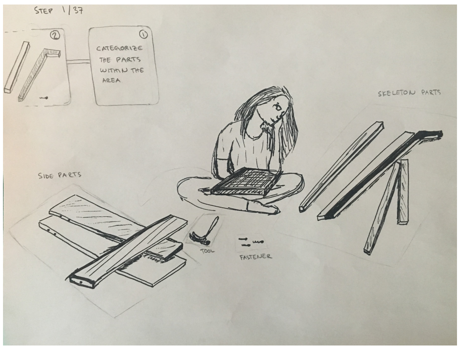
(a) First scene of the Mid-fi prototype.



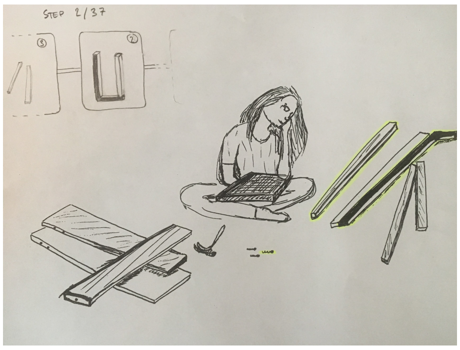
(b) Second scene of the Mid-fi prototype.

Figure 6.3: First part of the Mid-fi prototype.

The sketches were in total six and divided into three parts with two scenes in each part. Everything that was drawn with a pencil on the sketches, and not with a marker, was supposed to be visual represented in AR. The first part contained a scene, figure 6.3a, with the furniture in a smaller scale in AR together with the tools needed for the assembly process. The other scene showed two different assembly paths. One path was highlighted, which meant it was the suggested path for the assembly process. The idea was that the system should calculate the assembly partner's skill level with a rate of one to five stars, as shown in figure 6.3b, and then compare it with the user's own skill level to find the right assembly tempo. Thereafter, two different paths of assembly level should be suggested by the system, in this example a *Novice*-path and an *Advanced*-path. The "Novice"-path contained a longer assembly time with both more breaks and assembly steps, in comparison with the "Advanced"-path.



(a) Third scene of the Mid-fi prototype.



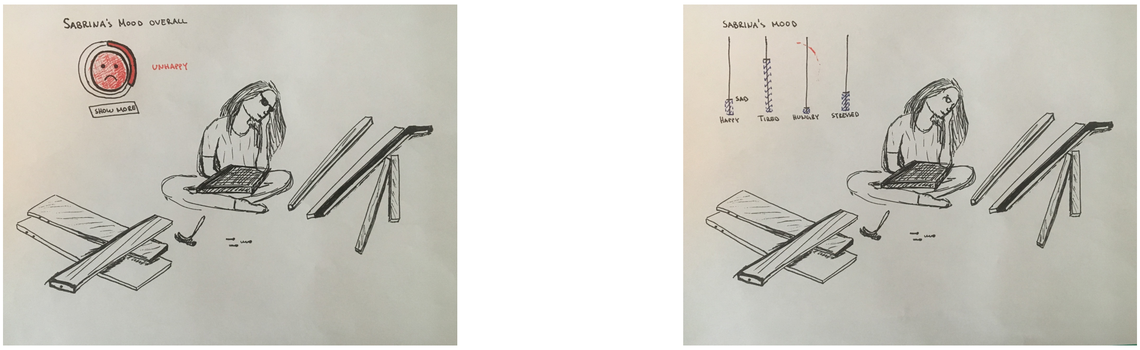
(b) Fourth scene of the Mid-fi prototype.

Figure 6.4: The assembly scenes of the Mid-fi.

The second part included the assembly scenes (figure 6.4. The first scene, figure 6.4a, showed the first instruction which was to categorize the different furniture parts within the

AR-area on the floor (side parts, skeleton parts, fasteners and tools). To the left of the first instruction was the second instruction shown as a shadow. Figure 6.4b showed the next instruction. In this instruction, the parts and the fasteners used in the step were highlighted in AR.

Figure 6.5 presented the third part of the Mid-fi prototype. This part showed an idea of how mood and emotion recognition could be a feature of the AR system. It could be efficient to let the system scan/read the overall mood of the people collaborating and their different mood status (figure 6.5b. In that way could the system for example calculate if it is the right time to assemble or not.



(a) Fifth scene of the Mid-fi prototype. **(b)** Sixth scene of the Mid-fi prototype

Figure 6.5: Scenes of the Mid-fi prototype with mood and emotion recognition.

A feedback meeting was held with three employees from the department at Ericsson. All of them were classified as experts. Two of them had experience with user interfaces and user experience and the third had a more back-end experience. All of them had participated in all previous design iterations of this thesis project. The goal with the meeting was to receive feedback on the Mid-fi.

The feedback was compiled in a bullet point list:

- Have a real-size model/hologram of the construction.
- Change "Skill level" to "Experience level". Also think about how this kind of level should be decided, a default mode or should the system be adjusted depending on the user.
- Show in the beginning of the assembly process an average time globally or somehow gamify the assembly process?
- Have a progress bar in every step where the progress is time based rather then activity-based.
- The "assembly area" should be adjusted to the physical room.
- Be consistent on the mood status bar (figure 6.5b) by using the opposite words on each side of the bar.

Chapter 7
Hi-Fi development

After the Mid-fi prototype, the design process continued with Hi-fi prototyping. The main focus with the Hi-fi development was to explore and evaluate phase three, *The visual interaction and feedback in AR*, mentioned in the beginning of previous chapter. The Hi-fi development was done on the game engine *Unity* for two of Microsoft's head-mounted devices, called *HoloLens 1*.

This stage begun with developer applications and tools were downloaded and installed on the computer. Then the equipment was set up and connected. Various online tutorials were conducted to learn the basics of the programs and some AR-functionalities. In the end, a Hi-fi prototype was developed and tested.

7.1 Prerequisites

Before the actually Hi-fi development could start, some prerequisites needed to be done first. The first step was to download and install different programs and all the developer applications and tools. Knowledge of how to use the programs and tools was also needed.

7.1.1 Software applications and tools

To get the AR development environment for a HoloLens application to work, A certain number of tools needed to be installed on a computer with Windows 10 operating system. *Windows 10 SDK*, which provided the latest headers, libraries, metadata, and tools for building UWP apps [26], needed to be installed. *Visual Studio 2019* was another important program from Microsoft, which is an integrated development environment for Windows [24]. There was also an option to download the *HoloLens emulator* to test some functionality of XR apps without a HoloLens [23]. Thereafter, a game engine was installed.

The chosen game engine was *Unity*. The reason for this was to use a platform with XR experience and that supports UWP which is an API created by Microsoft in Windows 10 [25].

The platform had also good documentation, forums and tutorials. The tool kit *Mixed Reality Toolkit* (MRTK) and the SDK *Vuforia* were also downloaded for the prototype development.

- **Unity**
  Unity is a cross-platform game engine developed by Unity Technologies. The engine supports more than 25 platforms and the users are able to create games and experiences in both 2D and 3D. The primary scripting API and programming language is C#. 60% of all AR and VR content is powered by Unity [36].

- **Mixed Reality Toolkit**
  MRTK is a cross-platform toolkit for building XR experiences for both VR and AR [20]. MRTK is created by Microsoft and provides a set of components and features to accelerate XR app development in Unity [20].

- **Vuforia**
  Vuforia is an engine widely used for AR development with support for smartphones, tablets and eye-wear [37]. This SDK uses computer vision technology to recognize and track planar images and 3D objects in real time. It supports variety of 2D and 3D target types. This includes "markerless" *Image Targets*, *3D Model Target*, and *VuMark* which is an addressable Fiducial marker.

7.1.2 Online tutorials

Various online tutorials provided a very good basis for getting started with the AR development. Microsoft, Unity and Vuforia had all tutorials that could be done. MRTK provided sample scenes which could only be tested.

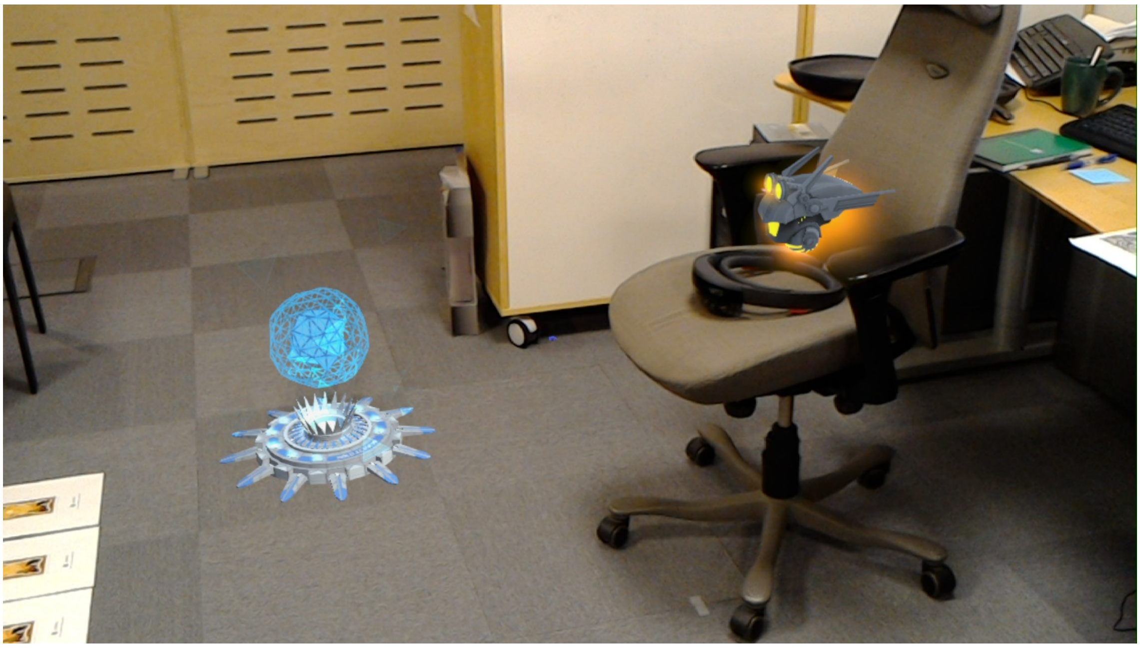


Figure 7.1: An image from the "Sharing-tutorial".

Ten of Microsoft's "MR-tutorials" was completed. That included all MR-tutorials called: Basics, Input, Spatial and one of the "Sharing-tutorial" called *Multiple HoloLens devices* [21].

The last mentioned tutorial was about how to setup a network for shared experience and how to share holograms across HoloLens devices.

Figure 7.2: An image from the the Vuforia's sample project were the VuMarks are tried out.

Vuforia provided a HoloLens sample project which was called *Vuforia Hololens Sample* but was in March 2020 updated and changed to Vuforia Hololens 1+2 Sample. The sample provided a complete Unity project showing how to design and configure Unity scenes to use Vuforia targets with HoloLens [34].

7.2 Setup of the development environment

The setup of the devices is shown i figure 7.3. Since the computer had issues with the usb ports, an alternative connection with a network adapter was applied instead. Therefore, all network communication was wireless and sent through a hotspot.

During the setup of the development environment, it was important that the computer's requirements met the system requirements for both Unity and Visual Studio.

To test the development project in Unity, the project scene was built in to a *SLN file* which is a structure file used for organizing projects in Visual Studio. The file contained text-based information about the project environment and project state [11]. The SLN file opened Visual Studio and the project was then started and remotely deployed to the HoloLens.

Figure 7.3: A schematic image of the development environment setup.

7.2.1 Microsoft's HoloLens

Microsoft HoloLens refers to *generation 1* and is a pair of mixed reality smart glasses developed and manufactured by Microsoft. This device was the first head-mounted display with Windows 10 computer operating system [39]. In November 2019, Microsoft released limited number of the successor to the HoloLens called HoloLens 2. HoloLens 2 has improvements as for example new hardware workloads as eye tracking and fully articulated hand tracking [38].

7.3 Hi-fi prototype

To begin with, the different versions of the software applications and the tools used in the Hi-fi prototype were:

- Unity: 2019.2.21f1
- MRTK: 2.3.0
- Vuforia: 8.6.10
- Windows 10 SDK: 10.0.102400.0

Vuforia sample project was taken as a starting point for the Hi-fi prototype development. The idea was to use the Image Target functionality on different furniture parts. In that way, holograms were shaped above the physical part when the image was scanned by the HoloLens.

This trick was used instead of implementing object identification in the prototype. Furthermore, MRTK was integrated with the Vuforia sample project in Unity. MRTK was of interest since there were a lot of UX based functionalities and component in the toolkit which were used in the prototype.

After Vuforia and MRTK were integrated, the fundamental functionalities of the prototype were done. Then the sample project was modified and developed based on the Mid-fi and the received feedback.

The goal in the beginning of the Hi-fi development was to integrate Vuforia, MRTK and the *shared experience* learned from Microsoft's "Sharing-tutorial". In the tutorial, the shared experience was done by establish a common reference point and then share the coordinates system, called *spatial anchor* [22], across the devices through a sharing server which was hosted by the computer. The shared experience was in the beginning of the Hi-fi development tried to be implemented but the functionalities were not compatible with each other yet. Unfortunately, this was not included in the Hi-fi prototype.

The structure of the Hi-fi prototype could be divided in to three parts, see table 7.1. The "Assembly process" in the table 7.1 was then further divided in to:

- **Step 0:** The step where the users were taking out the furniture pieces from the box and placed them on the corresponding hologram in front of them on the floor.
- **Step 1:** The step when the users inserted the four plastic fasteners in the holes on both side parts of the chair.
- **Step 2:** The step when the users inserted 16 wooden fasteners in the holes of the smaller wooden parts. Four fasteners on each part.
- **Step 3:** The step were the users inserted the smaller wooden parts on one of the side parts of the chair. The bent ones were the pieces to the back of the chair.

Table 7.1: The structure of the Hi-fi prototype with a description on what each part roughly included.

THE THREE PARTS OF THE HI-FI PROTOTYPE		
Part	**Prototype part**	**Description**
First	Introduction	- The AR assistant presented itself - A list with furniture, including the chair
Second	Preview-scene	- Scene with the tools and the chair that could be manipulated - A manipulation app bar - Assembly paths; Novice and Advanced
Third	Assembly process	- Four assembly steps - App bar menu with all functionalities - Image Targets with holograms

Since the chosen scenario for the thesis project was to furniture assembly, firstly a furniture had to be selected. The parameters that was important in the selection of the furniture was: (1) the furniture needed to be in the size that could trigger collaboration, (2) it could not be to big so it could easily be transported between the test sessions, (3) easy to unassemble after each test session and (4) have the tools available during the assembly process. Therefore, a chair [12] was selected.

Different free assets from Unity's asset store was downloaded to facilitate the modeling process. All the furniture and tools were downloaded models. The chair-model was then modified and in the open-source 3D computer graphics software toolset called *Blender* [5], so it looked like the physical chair [12].

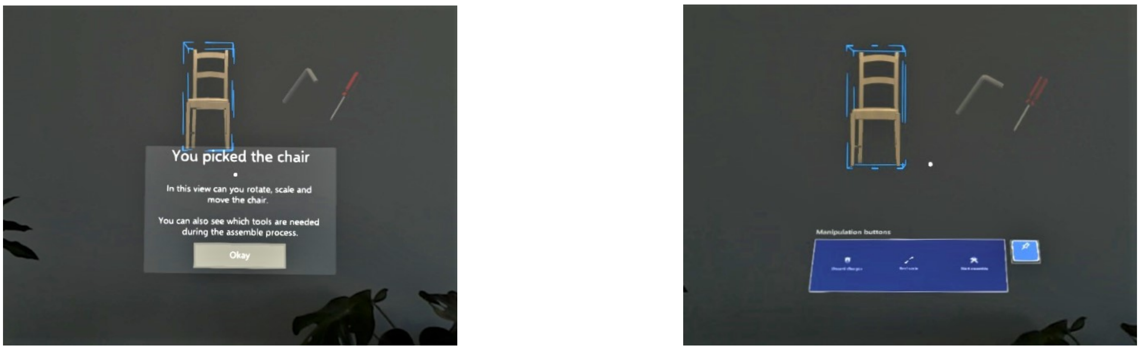
(a) The first view.

(b) The second view.

Figure 7.4: The scenes in the "Introduction"

The first two views of the entire Hi-fi prototype were those shown in figure 7.4. These two views represented the first prototype part "Introduction". In the first view 7.4a the AR assistant presented itself and in the next step a list of five different furniture appeared 7.4b. The user could choose between a lamp, a coffee table, a double bed, a chair and a cabinet.

When the user picked the chair, next prototype part begun - the "Preview-scene". The other furniture objects were not implemented, and on pressing a "negative" audio feedback sounded.



(a) The view with the assistant telling about the scene.

(b) The scene with the "Manipulation bar".

Figure 7.5: The "Preview-scene".

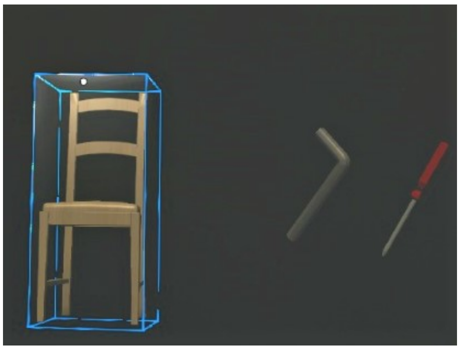
The "Preview-scene", see figure 7.5, contained the chair inside a blue 3D box, an allen key and a screwdriver. Both tools were rotating. An app bar menu was in front of the user which from now on will called *Manipulation bar*. The "Manipulation bar" could be pinned, unpinned and moved. By pressing on the highlighted button with a pin on (figure 7.5b), the bar menu were automatically moved to in front of the user but below the users chin. The "Manipulation bar" was now following the user's head gaze. The bar menu did also contain three buttons, from lest to right:

- **Discard changes:** The button picturing an icon with a waste bin on. When the user pressed the button, all previous changes were discarded and the chair was placed on its start point.
- **Real scale:** The button picturing an icon with two mirrored arrows on the diagonal pointing away from each other. When the user pressed the button, the size of the assembled chair was shown in real scale, see figure 7.6.
- **Lets assemble:** The button had an icon of two tools and when the user pressed on the button, the assembly process started.

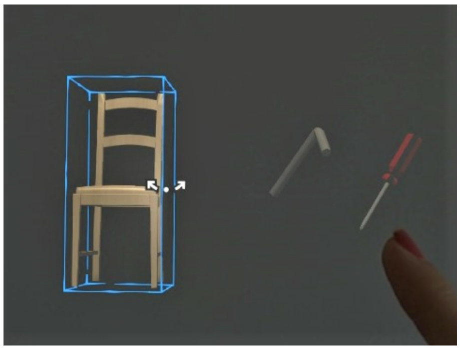
Figure 7.6: The hologram of the chair in real scale.

The chair in the box could be manipulated by the user. The user was able to move, rotate and scale the chair after their own preferences. The manipulation functionalities were implemented with help of the tools and components from MRTK. Figure 7.7 shows two of MRTK's implemented UX functionalities.

In next view, the AR assistant showed the two available assembly paths based on the user's and the user's assembly partner's experience skill from previous furniture assembly processes. The technique Wizard of Oz was used for this view. The idea was to present how AI could be integrated to the AR assistance by calculating which assembly rate is best suited for the users assembling. There were two options, but only one was implemented in the prototype: (1) the "Novice" path and (2) the "Advanced" path, see figure 7.8.



(a) When gazing on the chair, a white shadow appeared on the box.



(b) When rotating or scaling the chair, manipulation handlers appeared.

Figure 7.7: Two UX functionalities from MRTK.

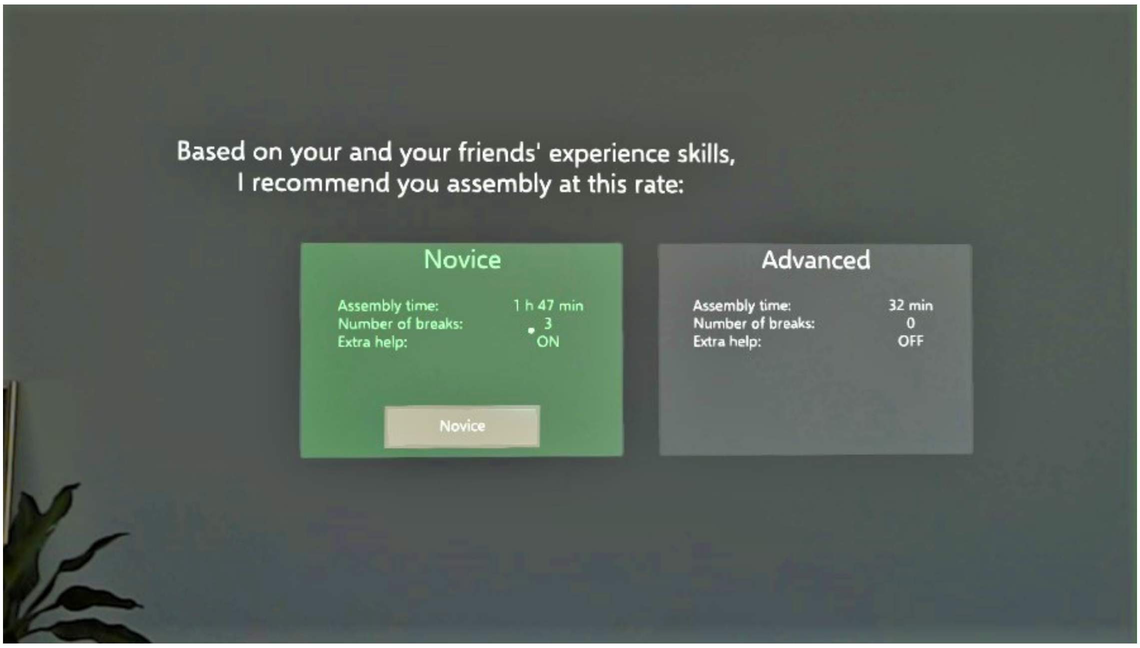


Figure 7.8: Assembly path calculated on the users' experience skill.

The third prototype part was "Assembly process" which was, as mentioned before, further divided in to four smaller steps. "Step 0" begun with two windows were prompted after each other.

The first windows which appeared showed information about the different functionalities in the app bar, which was not the same as in "Preview-scene". The app bar in this scene had three buttons, from left to right:

- **Extra help:** The button had an icon picturing a light bulb. When the user pressed the button, an image with a text explaining the instruction was showed. The image was adapted to the step and showed the completed state of the step. The text was a related sentence that described the instruction.
- **Progress bar:** The button had an icon picturing a progress bar. This functionality was not implemented.

- **Next step:** The button had an icon picturing a arrow pointing to the right. When the user pressed the button, the instruction changed to next step.

The second window gave the first instruction which was to place the similar furniture parts together in front of the users. In this step were all holograms revealed.

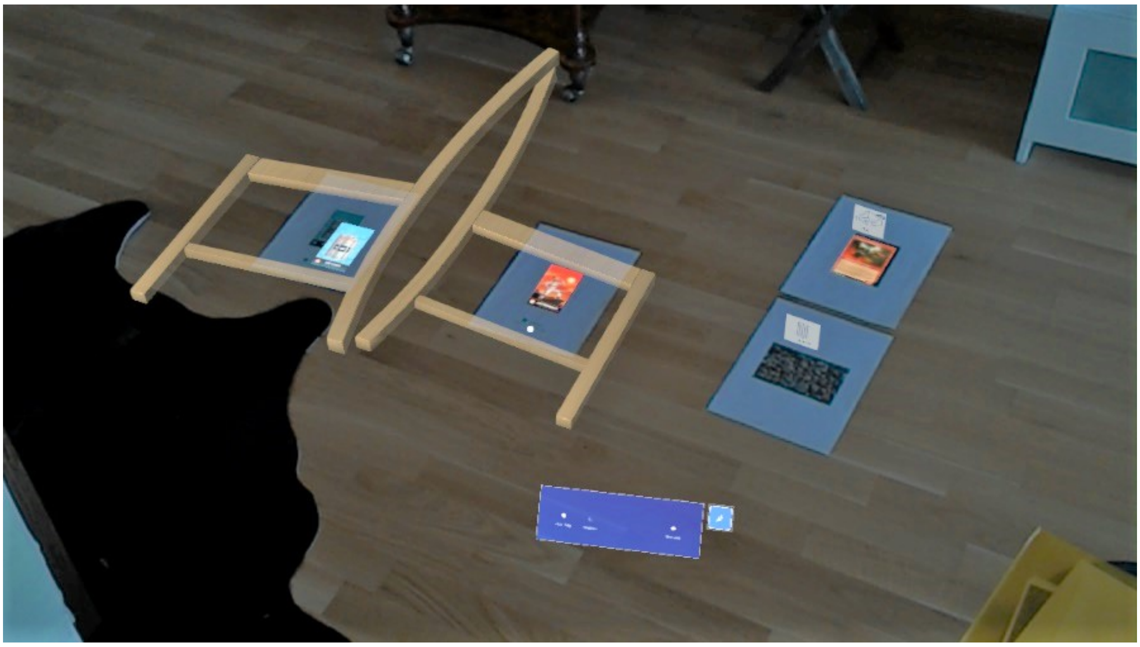


Figure 7.9: All holograms in "Step 0".

In "Step 1" the hologram showing the wooden fasteners was hidden. The goal in this step was to put the plastic fasteners in the holes on the side parts of the chair. The app bar menu contained in total five buttons. The order of the buttons from left to right was:

1. **Extra help:** Same as in previous assembly step but with a new image and text.
2. **Progress bar:** Same as in previous assembly step.
3. **Play animation:** The button had an icon picturing a play symbol in a box. When the user pressed the button, an assembly video was played. All step-by-step videos were recorded in advance. The participants were asked to imagine that the holograms were showing how to assemble them in an animation.
4. **Previous step:** The button had an icon picturing an arrow pointing to the left. When the user pressed the button, the instruction changed to next step.
5. **Next step:** Same as in previous step, but changes to next step.

The procedure and the app bar menues were the same in "Step 2" and "Step 3". Figure 7.10 shows which holograms were revealed during "Step 2".

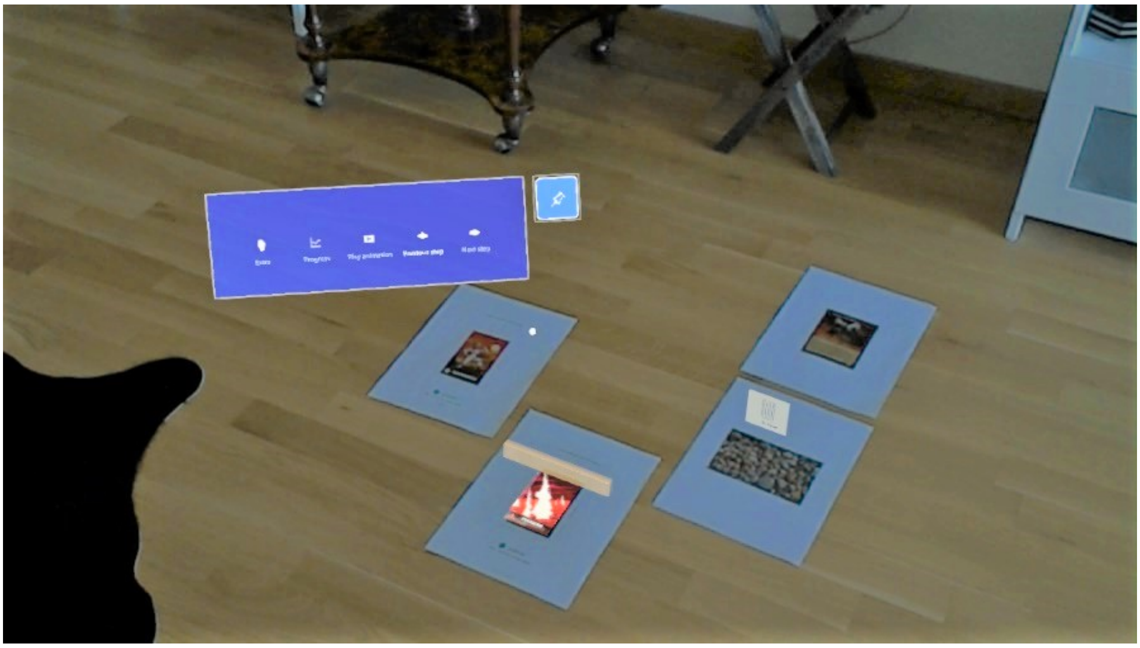


Figure 7.10: The holograms in "Step 2".

Chapter 8
Hi-fi prototype testing

This chapter is about to test the Hi-fi prototype by usability testing. The result and feedback from the tests gave an understanding for phase three which was to investigate the visual interaction and feedback of an AR experience.

The Hi-fi prototype was first tested in a *pilot study*. Then five usability tests on potential users were performed.

8.1 Pilot study

Before the usability tests were performed, a *pilot study* was done. The idea with a pilot study was to do a small run of the main study. This was done to make sure that the structure of the tests and the proposed method was viable [32, p. 293].

The pilot study was done by the supervisor from the university and the supervisor from Ericsson and took about 30 minutes. The pilot test persons tried the Hi-fi prototype and during the test, observations were written down. The application was the same, but each HoloLens deployed their own app. This was metaphorically explained to the test persons like this:

> *"Each HoloLens corresponds to a book. It is the same book with the same content, but two different ones. It is therefore important to be synchronized with each other so both are on the same page."*

After the pilot study, the pilot test persons gave feedback on the assembly experience. The participants thought the application was easy to understand and gave very good vibes through the whole experience. The visual and auditory feedback on the interactive objects and buttons gave a good user experience. They also liked the combination of the animation and the "Extra help" button. The improvements feedback is compiled in a list with bullet points:

- It was difficult to know where the physical chair parts should be placed in the room.
- The test persons needs to start in the same direction, otherwise there was a risk of either go bump into each other or the device would recognize the other test person's gestures.
- Add a functionality, in the assembly app bar, to hide the animation.
- Another idea was when pressing on the "animation window" the animation should be replayed.
- Bigger holograms on the furniture parts.
- Remove the "Progress bar" button since it was not implemented.

Two discussions appeared after the pilot study. One discussion was about which assembly instruction should by default encourage the user to press on, the animation or the image? The suggestion from one of the test persons was to change the content in "Extra help" with the animation and in that way let the extra help be the animation. The other test person did not agree to that, he preferred the other way around.

The second discussion was about the *pinned* assemble app bar. The participants, by default wanted to have the app bar during the assembly process toggled to the user.

The pilot study can be assumed as a evaluation on the first iteration of the Hi-fi prototype. All the improvements in the list were considered as important and were adjusted. The content in "Extra help" remained the same. Also, the pinned app bar in the assembly process was not changed because of the risk for users to miss the app bar. Since the pilot test persons are more familiar with AR, the last feedback was considered as a future improvement.

8.2 The performance of the usability test

A methodology of the test is presented in table 8.1. All tests were done in pairs and conducted in the *field*, which in this case was a living room. It is easier to find out how a prototype is adopted and used by the users in their everyday lives with a field study [32].

The test started by a pre-phase where the participants had to answer three questions about whether they speak English, if they have tried AR glasses before and if they usually wear glasses. The participant did also receive an introduction to the test session, see the instruction in Appendix A, and signed an informed consent, see Appendix B.

Afterwards, the participants put on the HoloLens and learned the basic interaction gestures on an on-device app called "3D-viewer". Before the participants started the AR assistance application (the Hi-fi prototype), they read through a given scenario which gave the participants a feeling of how the AR assistant was part of their everyday lives and what they were going to do. The aim of the test was to see if the users managed to assemble the chair [12] using the prototype application that had been developed.

Subjective quantitative and qualitative data was collected during the tests. The participants individually answered a questionnaire with demographic questions and a *SUS* survey, followed by a short semi-structured post-interview which was held in pairs to gather subjective qualitative data, such as:

- The participant's thoughts about the prototype. What they felt was good or if anything could be changed or removed.
- If there was any functionality the participants missed or thought would be necessary during the AR assistance.
- How the participants experienced their collaboration, what they felt worked well and less well.
- The participants thoughts of how and if AR assistance could be a solution during collaboration.

Table 8.1: The methodology of the test session including the resources.

THE TEST SESSION'S STRUCTURE				
Phase	**Task**	**Subtasks**	**Resources**	**Time**
Pre	Briefing	- Introduction - Answer three questions - Sign the informed script	- Orientations script - Informed consent	3-5 min
Pre	Prerequisite training	- Try out the AR-glasses - Try out 3D-viwer app	- 2x HoloLens 1	7-10 min
During	Test	- Read the scenario - Perform the test	- 2x HoloLens 1 - Unassembled chair - Tools; allen key & screwdriver - Video recorder - Notes	20-25 min
Post	Post-survey (individual)	- Answer on survey questions - Fill in the SUS survey	- Questionnaire - SUS questionnaire	5-7 min
Post	Debriefing	Supplementary questions	- Interview questions - Notes	15-20 min
Total				**50-70 min**

Figure 8.1: A test pair doing "Step 0".

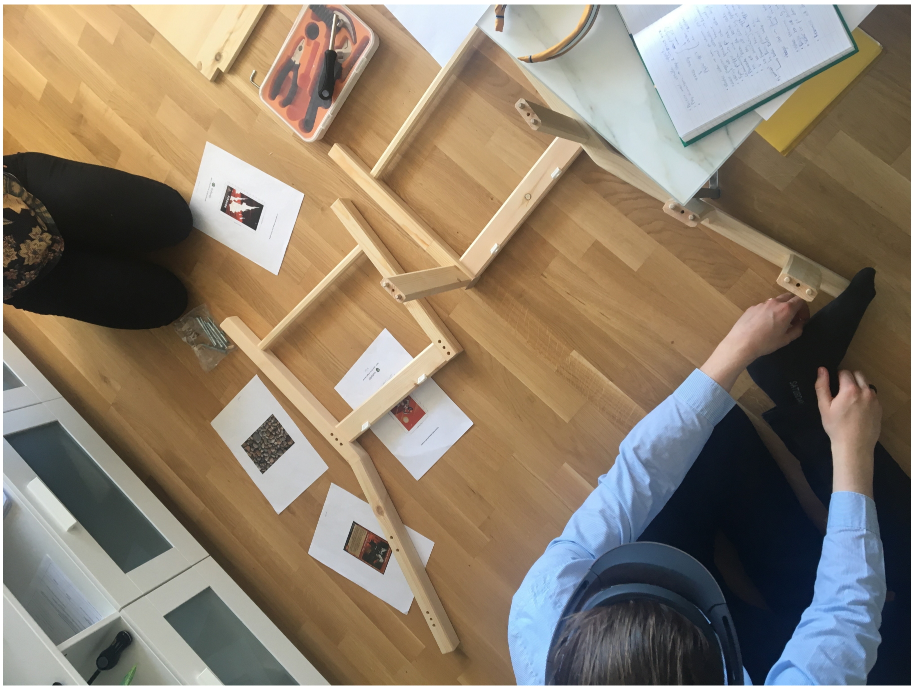


Figure 8.2: A test pair doing "Step 3".

8.3 Test plan

When the usability tests were planned, a *test plan* [9] was created. The goal with the test plan was to test if the developed Hi-fi prototype was usable by the intended target audience.

A already showed, table 7.1 in Chapter 8, shows the different prototype parts. During the test, quantitative data from only one part of the "Preview-scene" was collected which is the view where the user could manipulate the chair. This part of the scene will from now on be called *Manipulation scene*.

The "Manipulation scene" and the four steps in the "Assembly process": *Step 0*, *Step 1*, *Step 2* and *Step 3*, were relevant to evaluate in the test plan.

Different types of objective quantitative data was collected during each scene:

- **"Manipulation scene"**
    1. Number of users who tried all the various functionalities in the scene.
    2. Number of pairs who picked up the tools.
    3. Time spent on the scene.
- **"Assembly process"**
    1. Time to complete each scene.
    2. Number and type of error per scene.
    3. Number of clues from the test leader to complete each scene.

The scene "Step 0" had also the following measurement: Number of pairs who understood the link between the hologram and furniture parts.

Objective qualitative data was also gathered during the usability tests. Comments from the test persons were written down and the video recorded materials were analyzed.

Chapter 9
Results

In this chapter, the results from the usability test of the Hi-fi prototype will be presented.

9.1 Attended test participants

In total ten (n=10) participants participated in the usability tests. The tests were done in pairs, two and two. Table 9.1 shows each participant's age in pairs together with the pair's average age.

Table 9.1: The average age of each pair.

THE AVERAGE AGE			
Pair	**Age 1**	**Age 2**	**Average age**
1	22	24	23
2	21	61	41
3	25	30	27.5
4	26	28	27
5	26	26	26

30% of the participants were female (n=3) and the rest were male. Half of the participants were single or in a relationship. Three of the test persons were married, and two were in a domestic partnership. Most of the participants (n=5, 50%) where students and one person was MD-PhD student. Two participants were engineers, one participant was IT manager and one was junior doctor. In figure 9.1, the highest completed level of education among most of the participant's (n=5) was a Master's degree.

All participants spoke and understood English. Three of ten test persons had tried AR glasses before and four participants normally wear glasses.

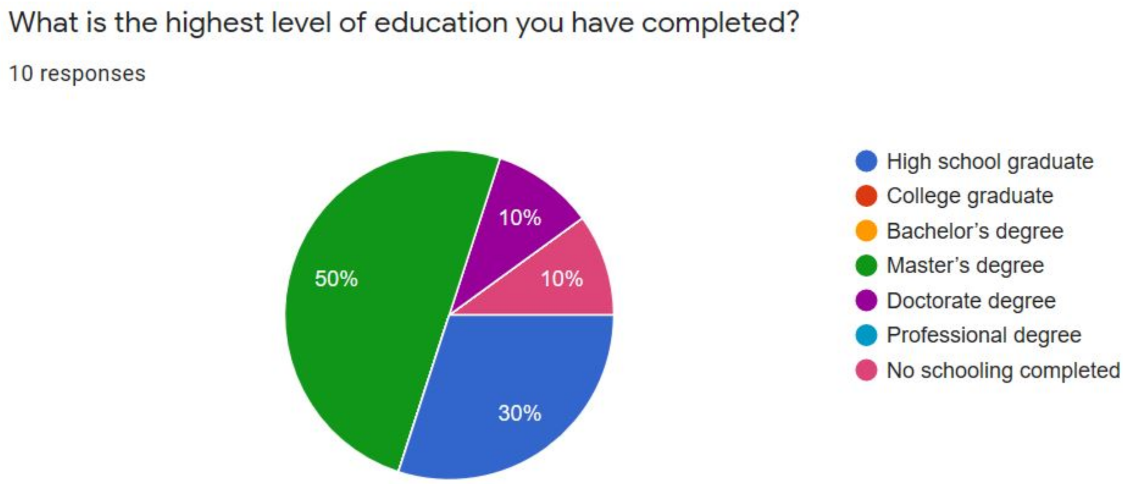


Figure 9.1: The distribution of the highest completed level of education among the participants.

The participants had all assembled a piece of furniture before, both alone and together with someone else. Most of the participant (n=9) had assembled a furniture more than 11 times and only one between 6-10 times. 70% (n=7) of the participant thought it was simple to assemble a furniture. Two test persons thought it was quite simple and one person thought it was quite difficult. Most of the participants (n=8) always uses the instruction manuals, while two of the participants only uses it when they can't solve it on their own.

9.2 Results from the usability tests

Table 9.2: The quantitative data collected from the Manipulation scene.

MANIPULATION SCENE			
Pair	**Q1**	**Q2**	**Q3**
1	No, not "Discard changes" & "Progress bar"	No	3 min 54 s
2	No, non of the functions	No	1 min 00 s
3	Yes	No	6 min 16 s
4	Yes	No	4 min 00 s
5	No, not "Discard changes"	Yes	5 min 41 s

In previous chapter, six bullet points was stated for the scenes "Manipulation scene" and "Assembly process". The three points related to the "Manipulation scene" were referred as *Q1*, *Q2* and *Q3* in table 9.2.

"Manipulation scene"

Q 1. Number of users who tried all the various functionalities in the scene.

Q 2. Number of pairs who picked up the tools.

Q 3. Time spent on the scene.

Table 9.2 shows the only two pairs who tried all the functionalities in the "Manipulation scene". Pair number 1 and 5 tried all different functionalities but not the button "Discard changes". Pair number 2 skipped all the functionalities and went directly to the "Assembly process". That is also the reason to why they spent least time in this scene. Out of all pairs, pair number 3 spent most time in this scene, followed by pair number 5. Pair number 3 had some troubles placing and moving the "Manipulation bar" as desired and therefore most of the time was spent on that. Compared to all other pairs, pair number 5 was the only pair that took out the tools from the toolbox.

"Assembly process"

1. Time to complete each scene (table 9.3).
2. Number and type of error per scene (table 9.4).
3. Number of clues from the test leader to complete each scene (table 9.5).

Every step in "Assembly process" was evaluated during the tests. The quantitative data collection from the "Assembly process" are presented in tables 9.3, 9.4 and 9.5. The column to the left in all three tables shows the different pairs. Each row has the measurements values for each pair.

Table 9.3: The first part of the quantitative data collected during the "Assembly process".

Pair	**Time to complete each step**					
	Step 0	Step 1	Step 2	Step 3	**Total time**	**Average time**
1	5 min 17 s	1 min 42 s	3 min 11 s	1 min 00s	**11 min 10 s**	**2 min 47.5 s**
2	6 min 02 s	3 min 02 s	2 min 16 s	-	**11 min 20 s**	**2 min 50 s**
3	4 min 49 s	1 min 39 s	4 min 39 s	9 min 56 s	**12 min 03 s**	**3 min 0.25 s**
4	10 min 05 s	1 min 23 s	1 min 11 s	-	**12 min 39 s**	**3 min 9.75 s**
5	5 min 07 s	1 min 58 s	2 min 14 s	4 min 42 s	**14 min 01 s**	**3 min 30.25 s**

Table 9.3 presents the collected data regarding the time it took to complete each step. Pair number 4 spent the longest time on "Step 0". Pair number 2 had the fastest total assembly time since they also managed to complete "Step 3" together with "Step 2". The pair that took the longest assembly time was pair number 5.

Table 9.4: The second part of the quantitative data collected during the "Assembly process".

Pair	Number and type of errors				
	Step 0	Step 1	Step 2	Step 3	**Total errors**
1	1*	0	1	0	**2**
2	1*	1*	0	-	**2**
3	0	0	0	0	**0**
4	1*	0	0	-	**1**
5	1*	0	1	0	**2**
Total	**4**	**1**	**2**	**0**	**7**

All pairs except pair number 3 made any errors, see table 9.4. Pair number 2 made twice *1**- error, which meant that the pair intended to press the "Next step" button to continue/receive the instruction, without actually completing the task. Since the test sessions were very much based on the test users telling what they saw, the error type 1* was therefore an important control state for the test leader. Pressing "Next step" was only done when the system (Wizard of Oz) announced that the step was completed. Unfortunately, this step couldn't be corrected and was therefore affecting the whole experience. Pair number 1 and 5 did both the same kind of mistake on "Step 2". They tried to put the straight short parts into the holes on the back of the chairs.

Table 9.5: The third part of the quantitative data collected during the "Assembly process".

Pair	Number of clues				
	Step 0	Step 1	Step 2	Step 3	**Total clues**
1	3	0	0	0	**3**
2	3	1	0	-	**4**
3	1	0	0	0	**1**
4	8	0	0	-	**8**
5	0	0	0	0	**0**
Total	**15**	**1**	**0**	**0**	**16**

Table 9.5 shows that pair number 4 used the most number (n=8) of clues from the test leader. Which was the double amount of clues than what the pair number 2 had, and they used the second most clues. All the eight clues the pair number 4 used, were only needed during "Step 0". Pair number 5 did not use any clues at all.

Only one pair understood completely the link between the holograms and the furniture parts and that was pair number 1. Pair number 2, 3 and 5 partially understood the connection. They understood that the idea was to place the parts from the box at the hologram, but missed that different holograms appeared during the assembly steps. Pair number 4 had in general troubles with "Step 0" and did not understand the point between the holograms and the parts. They partially understood the link after they had been given a clue about it.

Table 9.6: Every participant's SUS score.

Test person	SUS score	
1	70	Good
2	82.5	Excellent
3	80	Good
4	80	Good
5	95	Excellent
6	75	Good
7	85	Excellent
8	67.5	Poor
9	72.5	Good
10	85	Excellent

9.2.1 The participant's SUS score

After the usability test, each participant individually filled in a survey which contained the SUS statements. Every participants' SUS score was calculated and presented in table 9.6.

Test person number 1 and 2 formed the pair number 1, the test person number 3 and 4 formed the pair number 2, etc. 50% (n=5) of the participants thought the usability of the Hi-fi prototype was *Good*, even if the score of the participant number 2 and 3 is pretty close to the A-level. Only one SUS score pointed the system had poor usability.

9.2.2 Results from the interview & qualitative data

The interview was held in pairs and gave a lot of both new feedback explanations on some of the test person's behaviour during the usability test. This together with noted comments was presented.

All participants somehow reacted positively during the "Manipulation scene" when they pressed the "Real scale" button on the "Manipulation bar". Comments as *Wow, so big chair* and *I would like to sit on it* were comments from the tests. Many test persons tried also to place the chair on the floor to get it suited into the environment. During the assembly steps, the "Manipulation bar" and the "App bar" were not appreciated a lot by all users. All pairs expressed some frustration about the placement of the bar during any of the scenes. But during the assembly steps, most participants had become accustomed to the menu and focused on the assembly task. In two of the interviews, a suggestion to enlarge the bar and the buttons on the app bar could facilitate the interaction. Otherwise, the bar menu was considered as simple and intuitive with no unnecessary extra buttons.

The animation under the "Play animation" button, in combination with the image and the text in "Extra help", was appreciated by all users. However, all users who pressed the "Extra help" button during "Step 2" and "Step 3" got a bit confused. This because the images were the same and because the image did not match with the content in the animation. The holograms of the right and left side parts of the chair was also misleading. 4 of 5 pairs had trouble to match the real physical parts with the holograms since the hologram were missing the holes. This because the hologram was not designed with holes.

Test persons did like that the instructions followed the direction of one's head and the ones who did not prefer that functionality during the assembling were satisfied that they easily could hide them. However, during "Step 0", some pairs requested the opportunity to see the instruction again. With the fact that two windows appeared in a row, the windows felt, in a negative sense, as "pop-up" windows. The test pair number 1 explained during their post-interview that they usually don't read these kind of windows otherwise, they simply press the button to get rid of it. They further gave the idea that the assistant could be similar to how it works in the gaming world. There is always an opportunity to press a button and, for example, receive the task information on a required mission. In this way, the number of unnecessary clicks had decreased but also better adopted to the user's experience skill level.

During the "Assembly process", all participants began by pressing on the "Play-animation" button. Some of the pair succeeded to complete the task without the help from "Extra help". In two of the interview discussions, was it told that the title of the "Extra help" button was associated in a negative sense. Pair number 4 and pair number 5 interpreted the button as a *last way out* instead of *I am a novice and I need extra help*. They thought it was patronizing to press the button.

9.3 Future improvements

From the usability tests and the post-interviews, a lot of new ideas, suggestions and comments were given. If time had allowed, it would have been interesting to improve and change the prototype in a second iteration. The mainly improvements from the test session that would have been taken into account, would have been:

- When changing assembly step, let the "App bar menu" to remain in the spot where the user placed it in previous scene.
- Replace the side of the chair hologram with a correct model which includes holes.
- Clarify that there were two different kinds of smaller wooden parts by adding a hologram and write out the quantity.
- Clarify "Step 0" by for example telling the users to first open the box and then to take out all furniture parts and categorize them.
- Change the image on "Step 2" and divide the steps between the straight and the bent wooden parts.

Chapter 10

Discussion

10.1 Discussion about the results from the user testings

During the usability testing on the Hi-fi prototype, all pairs successfully completed all steps. The results showed that the usability of the developed AR solution was *good* This because most of the the SUS scores were above 68 (figure 9.6). If two of the users had scored 0.3 points more, the system's usability had then reached the *Excellent* level. This can be interpreted as the developed assembly experience was useful. Only one participated rated a score below 68. It is interesting to discuss if the usability of the AR prototype should be considered as Good/Excellent because of the SUS score results or if it should be considered the opposite? Due to external circumstances (see next section), the recruitment of the participants became family and close friends which is not preferable in this kind of research. Because they will be biased in the evaluation of the prototype and might score a higher grade just because they are impressed with the prototype.

In connection with the recruitment of the participants, the dispersion of the test persons was not large. As shown in table 9.1, the ages of the participants were close to each other. This can in turn be compared with the created personas. Only test users as the persona type *regular users* from the *user scenario 1* participated during the usability tests and evaluated the AR experience. Further, only one participant's age distinguished from the rest and therefore the average age of that pair differed from the other pair's. Beside of the age difference, the pair distinguished by not trying any of the functionalities during the "Manipulation scene". They did also take the longest assembly time on "Step 1".

As presented in table 10.3, pair number 4 spent almost twice as much time on "Step 0" in compare to all other pairs, even if they completed "Step 3" at the same time as "Step 2". Furthermore, the same pair needed eight clues from the test leader to success "Step 0". Pair number 2 were the fastest ones since they also manage to complete "Step 3" together with "Step 2". The pair that took the longest time was pair number 5 but they didn't use any clue from the test leader at all.

10.2 Answers to the research questions

- **How and in what way could AR and interaction design be useful for people collaborating with each other over a task?**

When reflecting back on the thesis project to answer the research questions that were written in the beginning of the project, it turns out that every step and decision in the project are the parameters that has led to the end result. If another person had been given the task to research the exact same questions, the result would probably have been different. The structure, the used methods and the development of the project had not looked the same.

Having said that, it turns out in the thesis project that there is a potential for AR to assist people during a collaboration. AR is still a very new and untested technology for many, even for people working within IT and technology. There are no fully established AR solutions in the consumer market yet, even less are there AR solutions for collaborations. But this is likely to change within the next decade. There exists a technological threshold in society that cannot be ignored. From having AR influencing some parts of the e-commerce and the social media, to becoming an assistant in one's everyday life. And yet challenging if AR should be an assistant in a collaboration. The transition needs to be as natural as possible. It may be too early to already now decide whether AR should be an actor in a collaboration or the game master itself, or maybe it could be both? Or, is it already now that decision needs to be made?

However, this thesis doesn't evaluate the psychosocial relationship between human and technology, but it is definitely an underlying fact that must be kept in mind. As mentioned before, this project shows that AR could be used in a collaborative assembly scenario. The interaction design from a usability aspect, plays a key role.

There were a lot of different ideas presented in the results of Chapter 5, on how AR could be useful for people collaborating. From the focus group, several use areas were AR could be integrated were mentioned. All were situations that were somehow taken out of the everyday life, as for example collaboration at home and at work. AR could facilitate a lot of scenarios by calculating and making measurements in advance based on machine learning and AI. For example, when cooking or baking, AR could give instructions step-by-step, calculate how many scoops that have already been put in the bowl, keep track of how long the onion needs to mill in the frying pan and where the chicken fillet should be cut. AR can also be used to build a perception of where to place a furniture in the room.

The combination AR and interaction design was tried out both on a Lo-fi and a Hi-fi level. It was important to investigate which interaction modality to use between the user and the system. Different modalities were tried out on a Lo-fi level to see which one felt most intuitive. It turned out in this thesis that the interaction modality with least interaction, was the preferable modality in a collaboration in pairs. With other words, most participant preferred the modality where the system automatically understood the state and changed to the next step. But it is important to mentioned that this is not mutually exclusive. However, they all agreed on that multimodal interaction with voice command was the best alternative. Voice commands could be unwieldy in a collaboration, because then it can be difficult to discern if the conversation is to the other person or to the system. Many voice assistants as Apple's Siri, Amazon's Alexa and Microsoft's Cortana uses a wake word to detect and record the spoken request. Maybe that could be a natural way to introduce an AR assistant in the everyday life, because then there is an association reference to something that already exists today.

- **Sub-question 1:** What AR and interaction objects are of interest?

From the Lo-fi tests the functionality of the progress bar was considered as very important, regardless of the user's previous assembly experience. Due to time constraints, this functionality could not be developed for testing with the Hi-fi prototype. The corrective feedback was not implemented in the Hi-fi prototype because of the same reason, but was considered as an important interaction qualification during the Lo-fi tests. The animation during both prototypes was very much appreciated. Instead of pure text, the animation was the whole instruction and played therefore a fundamental role during the assembly task. In the Hi-fi prototype the combination of the animation and the content in "Extra help" the best combination according to the users. Another AR objects that were appreciated by the users before the assembly process, was the construction that was going to be built and the tools.

- **Sub-question 2:** Which information and feedback are needed during the task? And is it presented differently depending on the user?

The most important information needed during the assembly task was the instructions - the animations. Otherwise it was difficult to assemble. Even if it was only one pair during the usability test who understood completely the link between the holograms and the furniture parts, the very hologram feedback was considered necessary. Three of the pairs used the feedback when taking out the parts from the box. Corrective feedback was not implemented in the assembly application but considered as important. This type of feedback is a way to show the user what has happened after their action with the system [28]. The only feedback tested was visual feedback in AR. Neither the Lo-fi prototype nor the Hi-fi prototype provided different information and feedback depending on the user. But an idea was proposed to have the relation master/slave between the users collaborating, were the master had the control power of the assembling task. The suggestion was not appreciated during the focus group in the second iteration of the Lo-fi development. The participants agreed that the information and feedback should be presented equally to all participants in every assembly step without dividing the step into smaller individual steps. They considered the AR system as a collaboration tool where all participants should be included.

- **Sub-question 3:** Does the solution provide different assistance for the people collaborating?

In the Mid-fi prototype, the idea with different paths based on the users' experience skill level was designed. The system needs to be adaptable to the user and in that way contribute to improve the user experience. Since furniture assembling has a wide target audience, the AR assistance needed to be suitable to the user's level and in that way provide the best experience for the user by offering different assembly paths.

In the Hi-fi prototype, the users had two alternatives, "Novice" and "Advanced" but could only choose the "Novice" path. This was not further commented by the test users, except that some of the test persons had commented that they considered themselves to have more advanced skills than a novice. Therefore, this was not tested since none of the developed prototypes did provide different assistance for the people collaborating.

10.3 Obstacles during the thesis project work

There were several of obstacles during the development process of the Hi-fi prototype. Due to Ericsson's network restrictions and blocked USB port access, it took some time to figure out a solution to the development environment setup. The work computer at Ericsson had neither the capacity nor the processor to maintain a development environment nor the ability to download all the software programs that was needed, it took about one month to get a developer computer. The idea in the beginning of the thesis project was to develop a Hi-fi prototype on another HMD than HoloLens. This was later changed and it took then another month to receive the HoloLenses from an Ericsson office in the US.

A huge issue in the beginning of the Hi-fi development was to manage to integrate Vuforia with MRTK in Unity. The packages couldn't be merged with each other because of camera rendering problems. MRTK used its own *Main camera* as a child to the *Playspace* which ensured the headset and other required systems were managed correctly in the scene [20]. While Vuforia needed its own *AR camera* to manage to handle the Image Targets. It was therefore a rendering problem between the cameras since the HoloLens didn't knew which camera to use and was destroyed on the deployment. This was solved by not allow MRTK by default to put the AR camera as a child to "Playspace". This was a bug from Unity and Vuforia and was later fixed in Vuforia's updated sample project [34].

Another bug that appeared during the Hi-fi development without making large changes in the project or importing new packages, and prevented the Unity project to get built. The same errors was given even on the working project backups. Eight errors were given telling the same message but different 'names':

"The namespace name 'Editor' does not exist in the namespace 'UnityEditor' (are you missing an assembly reference?)"

The problem was that a file called "Dwell" randomly was placed in another file called "Editor" and was disturbing the project's build. Deleting the "Dwell" file solved the problem.

The biggest negative impact on the thesis project, that mainly affected the whole Hi-fi development and the all testings, were the *Coronavirus disease*, known as *COVID-19* [41]. It was an external circumstances that could not be avoided. After an international trip and a travel restriction from Ericsson, the thesis author needed to stay away from the Ericsson's office 14 days. When 14 days had passed, most of the department at Ericsson was asked to work from home instead. Unfortunately, this affected the Hi-fi development in time and also limited the number of people who tested the Hi-fi prototype. It was hard to get people from the department to test the AR prototype.

10.4 Possible error sources

Most of the design decisions in this thesis project were based on subjective qualitative data. During the development and the testing of the Lo-fi prototypes, the group of participants were a homogeneous group. All participants were male, over 35 years old and worked within data and IT. Everyone except of one participant worked at Ericsson. This is a common factor in this industry since it is male-dominated. In a human-centered development where the target audience is large as in this project, it is important that all potential users are somehow represented. Otherwise is there a risk that the design will only suite just one type of users.

The same problem applied to the respondent on the online survey since most of the respondents were between 15 to 34 years old and students. The distribution of the respondents depends on the environment in which the survey were sent. The questionnaire was posted on Facebook, which will then attract respondents with similar demographic information and background as the author of the thesis project.

(a) A participant tried to read the text on a hologram.

(b) A participant were bending forward to scan an Image Target.

Figure 10.1: Two types of cases where HoloLens is not adapted to the users.

This thesis project was not about evaluating the HoloLens, but the fact is that the results of the Hi-fi tests gets affected by it. It was only three test persons that had tried AR glasses before and the users' AR experience gets affected of the HoloLens as a device. If the participant hasn't tried to wear a HoloLens before or how knows how to interact with it, its affects the whole experience negatively. The HoloLens can be perceived as heavy and clumsy. And when you bending forward, the device gets heavy and can fall off. Therefore, the user needs to keep the HoloLens on the head by using their hand as in figure 10.1b. If you tighten it too hard, it can also trigger tension headaches, as it did for two of the test participants. In addition, the HoloLens is not suitable for people with visual impairments or for people who are blind. Four test persons said in the beginning that they normally uses glasses and one of the participants was actually wearing glasses together with the HoloLens during the test. Figure 10.1a shows when one participant had trouble to both see and read the text on the "App bar" menu.

It is also important to mentioned that this project didn't take into account if the participants, during the usability tests, know or have been collaborating with each other before. Which also plays a role in the evaluation of the AR experience.

Chapter 11
Conclusions

The full potential of AR is today not used yet. That is partly due to that different technologies are not integrated yet but mainly because of there is no device suitable to provide the best AR experience.

The thesis project has been a conceptual design development with an iterative human-centered design process. The scope of the thesis work was to explore how AR could assist a collaboration between users in a furniture assembly task. The focus has not been on the technical aspects of the development but rather conceptually to come up with prototypes and test them. In that way new insights were received and could iteratively be improved and tested again.

The research of this thesis shows that there is a potential for AR to assist people during a collaboration. Every collaboration looks different. A collaboration depends on who is collaborating with who and how many are in the collaboration. It also depends on where the collaboration will take place and what kind of collaboration task it is.

This thesis could be used in the future to further explore how to design an AR assistant that could be used during a collaboration. It is not necessary to be within furniture assembling, it could be applied in various application areas. The foundation for the research development would still be the same, the three different phases are important and are needed to be investigated. This because it might look different depending on the collaboration scenario.

In the future it would be interesting with a further prototype development of the Hi-fi prototype where object detection is integrated. But also combine it with a visual marker or some kind of 3D modeling program. It would also have been interesting to look into Mark Billinghurst's research area and develop a remote collaboration experience and explore how to integrate embodied holographic avatars.

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Appendices

Appendix A
The orientation script

Orientation Script

Hej,

Jag välkomnar er hit och vill börja med att tacka er för ni vill ställa upp som testpersoner i detta användbarhetstest!

Detta test är utformat av mig för mitt examensarbete på Ericsson och Lunds Tekniska Högskola. Mitt namn är Lia och jag kommer både tala med er samt agera som en del av systemet genom detta test. Jag kommer att dokumentera testet i form av bild och ljud. Därför vill jag be er att skriva under ett informerat samtycke, tack.

Idag kommer ni att delta i ett test där ni kommer att utvärdera användbarheten på en AR-prototyp som är skapad för examensarbetet ”Interaction design for Collaborative AR Task Solving scenarios”. Testet är uppskattat att ta mellan 60–70 minuter men det är ingenting ni behöver tänka på under sessionen. Ni får gärna ställa frågor till mig under tiden ni genomför testet, men vill uppmärksamma att jag eventuellt inte kommer kunna svara på alla frågor.

Innan vi sätter igång med testet kommer ni att få prova en enkel app på AR-glasögonen för att komma in i AR-miljön.

Jag vill påpeka att ni har rätt, närsomhelst under testet, att avbryta sessionen.

Det som kommer att hända under testet är att ni kommer först få läsa ett inledande scenario och sedan sätta på er AR-glasögonen. Jag kommer sedan sätta igång prototypen där ni gemensamt och med era tidigare kunskaper, ska försöka montera ihop en möbel med hjälp av prototypen.

Jag vill poängtera att detta inte är ett test av er prestation att genomföra uppgiften utan jag vill se brister i designen av prototypen. Jag ser gärna att ni talar om högt och tydligt både för mig och för varandra om varje steg/moment som ni både ser och gör. Berätta gärna om utmaningarna ni upplever samt övriga kommentarer som dyker upp.

Efter testet vill jag gärna att ni individuellt fyller i ett till frågeformulär rörande testet ni nyligen genomfört. Därefter ska ni gemensamt svara på några frågor. Är det någonting som verkar oklart?

Appendix B
The informed consent

Informerat samtycke

Jag samtycker till att frivilligt medverka i en användarstudie av AR-prototypen för examenensarbetet ”Interaction design for Collaborative AR Task Solving scenarios”.

Jag tillåter att sessionen videoinspelas och att inspelat material endast kommer att användas internt inom forskningsgruppen för examensarbetet.

Jag är informerad om att mina personuppgifter och mina resultat behandlas konfidentiellt och presenteras anonymiserat.

Jag är medveten om att jag när som helst kan avbryta sessionen, utan att ange orsak.

Datum:
__________________ den ___/___

Namntecking

____

Namnförtydligande

____