UNIVERSITY WEST
*School of Business, Economics and IT*
*The Division of Informatics*

# *Examining the performance of AR technologies to provide instructions for operators: a study at Siemens*

*Bachelor Thesis, 15 HE credits*
*Supervisor: Karlsson, Jan-Olof*
*Examiner: Jobe, William*
*Date: 2020-05-01*

**Zellaya, Ibrahim** **Brushwood, William**

# Content

# Terminology

- **Augmented Reality** - A technology used to give a user the ability to view virtual object in his/her real world.

- **Virtual Reality** - A technology that completely immerses a user in a virtual world, excluding him/her from the real world.

- **Acceptance model** - A model/theory used to determine the user acceptance of a technology/artifact.

# Figure overview



# Table overview

# Sammanfattning

Siemens Industrial Turbomachinery AB är intresserade av att digitalisera deras arbetsprocesser. Således är syftet med denna studie att undersöka om AR presterar bättre än papper som en instruktionsmetod för operatorer på Siemens i Trollhättan. För att kunna svara på frågan "Hur väl presterar Augmented Reality (AR) teknik som instruktionsmetod till skillnad från papper för operatorer i en produktionsmiljö?", har två kvalitativa metoder tillämpats. Datainsamling skedde med hjälp av observationer och *semi-strukturerade intervjuer* för analys till studien.

Vårt val av teoretiskt ramverk tillämpades inte endast för att undersöka prestanda, det användes även för undersökning av operatörernas vilja att införa AR som en instruktionsmetod.

Resultaten från denna studie visar att AR presterade bättre som en instruktionsmetod och att operatörerna hade en positiv inställning vid användning av AR. Däremot, är det fortfarande oklart hur väl denna teknologi kommer att accepteras. Detta beror huvudsakligen på faktum att framtida förbättringar behöver utföras när det kommer till hårdvara och avsaknaden av skräddarsydda applikationer för operatörernas behov.

**Nyckelord:** Tillverkning, Teknologi, Augmented Reality, Industri 4.0, Operatörer, Teknisk dokumentation, TAM, Huvudburen display.

# Abstract

Siemens Industrial Turbomachinery AB is interested in digitizing their current work processes. Therefore, the reason for this study is to examine if AR performs better than paper as an instruction method for operators at Siemens in Trollhättan. In order to answer the question "How well does Augmented Reality (AR) technology perform compared to physical papers as an instruction method for operators in a production environment?", two qualitative methods have been applied. Data was collected by using observations and *semi-structured interviews* for the analysis of this study.

Our choice of theoretical framework was not only applied for evaluating the performance, but also the operators' willingness to adopt AR as a form of instruction method.

The findings from the results show that AR performs better as an instruction method and that the operators had a positive attitude when using AR. However, it is still unclear how well this technology will be accepted. This is mainly due to the fact that future improvements still need to be made to the hardware and the lack of customized applications for the operators' needs.

**Keywords:** Manufacturing, Technology, Augmented reality, Industry 4.0, Operators, Technical documentation, TAM, Head-mounted display.

# 1 Introduction

As it appears, the manufacturing industry is undergoing a big change, which means moving on from traditional working methods and replacing it with digital alternatives. One component of this change is the use of virtual technologies and in this study, we are here to find out if such a change would work.

In the following episode, we will provide background information about the foundations that this study is built on. An indirect reason for this study is the fourth industrial revolution or the term “Industry 4.0”. What is mainly driving this study, is the company Siemens Industrial Turbomachinery AB. Industry 4.0 is what drives Siemens to such change, which means it also indirectly drives this study too. Siemens specializes in many areas, but in this case, it is all about Industrial Turbomachinery. Industry 4.0 combined with digitization sparks companies’ interests. In this case, we are talking about Siemens moving on from traditional working techniques, such as physical paperwork, to something more digital, namely AR.

## 1.1 Background

The term fourth industrial revolution was introduced in 2011 by the German association ”Industrie 4.0”, Ardito et al. (2019) explains. The association was composed of scholars, executives, policymakers and they hinted that the revolution was based on businesses digitizing their work processes. The main idea behind this revolution was that businesses were able to adopt digital technologies which could establish connections between their supply systems, production facilities, and machinery to gather and share real-time market and operational information (Ardito et al., 2019).

Today this industrial revolution is challenging for many industries to change and adapt their businesses to compete with their competitors. For this to be achieved many industries are investing in new technologies that will lead to reduced decision-making and more manufacturing ability. In this highly competitive business market, manufacturing industries are faced with producing products at reduced time-to-market (Ong et al., 2008).

Siemens Industrial Turbomachinery AB is one firm that is interested in looking into the possibilities of implementing AR or Virtual Reality (VR) as a useful tool for their machine operators. The firm supplies the world with gas turbines and gas turbine-based solutions for a sustainable and cost-efficient production of electricity, steam and heat. The turbines are also used as power sources for compressors and pumps, mainly in the oil and gas industry. They have approximately 2,700 employees, most of them are based at the head office in Finspång and 120 work in Trollhättan (where this study was conducted).

Currently the machine operators at Siemens are given instructions in a traditional form of paper documentation. The operators will normally use a computer to print out their instructions in a Portable Document Format (PDF), before they can start with their manufacturing tasks. Therefore, according to Dangelmaier et al. (2005), AR or VR can be used as a new way of replacing traditional instruction manuals.

The manufacturing facility in Trollhättan produces combustion chambers for the turbines on a relatively low production scale. Production tasks at Siemens are rarely the same and operators do not have certain tasks that occur regularly. That means operators never get used to a certain assignment. Connecting this fact with the instructions that the operators work with, it is a good reason to invest in instruction methods. If the same tasks would occur on a regular basis, the operators would probably memorize the instructions and learn to complete the task at hand without it. Now that this is not the case, it is of interest to further investigate and find improvements for the instruction methods.

## 1.2 Previous studies

### 1.2.1 Extended Reality

With Extended Reality, in this section, we mean both VR hardware, a VR Head Mounted Display (HMD, also known as a "headset") or AR hardware, an AR HMD. In VR the user is completely surrounded by the virtual world, while in AR, the user is able see and participate in the real world but also able to see virtual objects. In other words, when using AR, the user is still in the real world, but can now experience virtual objects in his environment. Since both remain a virtual technology, we will refer to them as "XR" (Fast-Berglund et al., 2018).

XR has already been implemented in various scenarios within industries. Not only can XR be used as a method of providing instructions for operators, it can also be used for simulation of important tasks (Aurich et al., 2009). Aurich et al. (2009) also explain that XR is typically used for planning purposes. In an industry environment, this is very useful when implementing new tools, robots or storing shelves. Aurich et al. (2009) mean that the use of XR can provide a visualization of future product designs and can also be useful in the process of training employees.

De Souza Cardoso et al. (2020) explained that previous studies have argued on the fact that operators need their hands and visual field free most of their time working. This sparks interest in using AR for this study, since the hardware in this case would be worn on the operators' heads and therefore will not limit the use of their hands.

Alternatives on hardware for this study could be VR, but that would "conceal" the operator from the real world which is both dangerous and impractical in a production environment (Ong et al., 2008). Therefore, AR is the more suitable technology in this case. However, it would be interesting to compare both AR and VR, but this is not possible because we only had access to AR hardware for this study. The type of AR that we had available was a Head Mounted Display (HMD), HoloLens by Microsoft. This was mentioned briefly by Gattullo et al. (2019) and they described this hardware as a relatively low-cost HMD with a high resolution and the possibility of using voice commands and the ability to 3D scan the real world surrounding the user.

### 1.2.2 Pros and cons with AR

Previous work has provided both positives and negatives of AR. This study is based on AR technologies and how well they perform. Therefore, knowledge about AR is of importance. The reasoning behind the importance of performance (for an instruction method) is based on the pressure that is being placed on the manufacturing industry. Consumers are demanding innovative products at a high manufacturing speed (Ong et al., 2008).

According to Agostini & Nosella (2019), AR is one of the leading technologies that has been presented in this context. AR can be described as a new form of man-machine interaction, where computer-generated information is shown in the user's real field of view (FOV). This technology provides a seamless interaction of the real world and virtual objects. Masood & Egger (2020) highlight that in industrial operations, AR can be used as an important tool to improve process efficiency and flexibility. This can be obtained with real-time and hands-free information. It is estimated that the annual growth rate for AR in the industrial market is projected to be around 74% between 2018 and 2025 (Masood & Egger, 2020).

Benefits of AR, brought up by Fiorentino et al. (2014), would be increased time and cost efficiency. Yet, we have seen other studies (presented below) that claim otherwise, regarding AR and its benefits. In order to objectively get a hold of real answers, we had to take a look at the challenges previous studies have encountered regarding AR. When taking on previous work, we found out that one of the biggest challenges was user acceptance (Masood & Egger, 2020). Overcoming this challenge would mean large success, but failing to do so would be a bigger problem, Masood & Egger (2020) explain.

Other impactful factors, such as hardware issues and limitations have to be taken into consideration. A few examples of the issues presented by both De Souza Cardoso et al. (2020) and Uva et al. (2017) would be the excessive weight of the hardware, which could cause the user (or in our case, the operator) fatigue. Other issues mentioned about the current technology was a small FOV or a low-resolution device, which could cause headache and nausea (De Souza Cardoso et al., 2020).

## 1.3 Problem area

Previous work about AR, made us question the benefits of this kind of technology. De Souza Cardoso et al. (2020) address that AR can have impacts on the environment and that this technology demand should be compared with traditional methods. This in turn can attract investors to the technology if the results are better than traditional methods or maybe lead to proposed changes to AR devices. AR technologies include new hardware that can change current work processes which lead us and Masood & Egger (2020) to believe that acceptance models should be incorporated to analyze the User acceptance, as this is a serious challenge to overcome.

Since the negatives in the current AR technologies may have health impacts on the individual operating the device (De Souza Cardoso et al., 2020), (Uva et al., 2017), we had to keep in mind that such factors could drag down motivation and willingness of use. Other problems also remain open such as the usability and the learning effect due to the repetition of a procedure at different times. These variables became of interest to evaluate the effect on user performance, as this is what Uva et al. (2017) pointed out from their study. With all these problems mentioned, it could affect the overall user acceptance of AR devices, which in turn, made this study even more relevant. What also supported our case was our failure to identify previous literature that has attempted to study AR technologies in a real production environment, with the operator performing authentic tasks.

## 1.4 Research question

This study aims to answer the following research question: ***How well does Augmented Reality technology perform compared to physical papers as an instruction method for operators in a production environment?***

# 2 Theory

The theoretical framework chosen behind this research is the Technology Acceptance Model (TAM). The TAM model was originally constructed by Davis (1989). Originally the TAM model proposes *Perceived Usefulness* and *Perceived Ease of Use* as beliefs towards new technologies. In our case, it would be how well an operator accepts using AR as an alternative to papers. In addition to that, how well the AR HMD performs as an instruction method. This theory has been validated by scholars as a robust and generous framework for understanding user acceptance of technologies such as banking technology, mobile-commerce, e-commerce self-service technology and mobile-television (Manis & Choi, 2019). The main reason for choosing this theory was that it enabled us to identify factors that need to be taken into consideration for the ability to evaluate the user acceptance of a digital artifact (Mantis & Choi, 2019). Below, you can find a "roadmap" of how the proceedings happen when applying this theory.

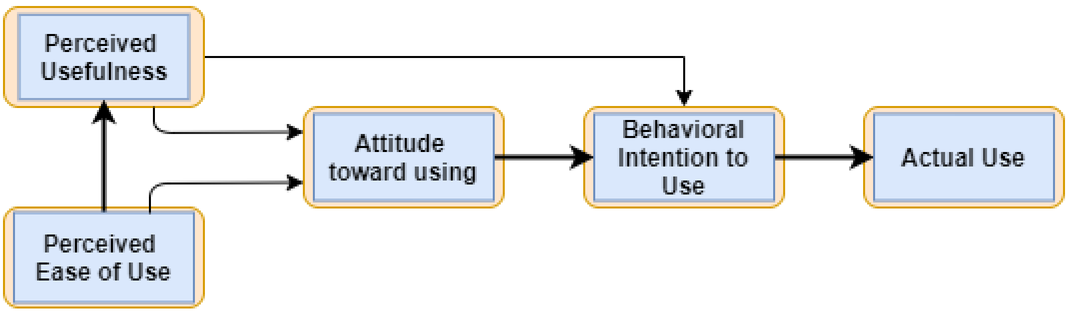


Figure 1. Technology Acceptance Model (Davis, 1989).

People tend to either use or not use new technologies depending on if they believe it will help them to perform their work tasks better. The *Perceived Usefulness* variable in the TAM model is described by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance". At the same time potential users might also believe that new systems will be difficult to use, this variable is referred to as *Perceived Ease of Use*. Perceived Ease of Use was originally defined by Davis (1989) as "the degree to which a person believes that using a particular system would be free of effort". Davis (1989) means that a technology or application that is perceived easier to use than the other is more likely to be accepted by users. The two previously mentioned variables in this theory have a significant role in deciding and understanding the user's acceptance towards new information technologies.

# 3 Methodology

The goal of this study is to identify what method is the better alternative. For the ability to do so, we took relevant variables into the equation, such as time to complete a certain process and any difficulties that might appear. However, we also took the user acceptance into consideration, as previous studies showed that the results of such a study might be affected by this factor (Masood & Egger, 2020).

The research setting was to do a study on one single company, in a specific facility. Therefore, this study remained qualitative. Backman (2016) points out certain benefits of qualitative studies. In qualitative studies, individuals shape and perceive their own reality (Denscombe, 2018), which is exactly what this study is looking for. You could say for the most part that this study was directed towards Siemens, since the outcome of this study provides answers only for this specific company. The results of this study cannot be applied globally. What works for Siemens, for example, might not work for Microsoft.

As for the hardware that was used, it was a Gen. 1 AR HMD by the name HoloLens, made by Microsoft. The AR HMD is worn like a typical VR HMD, around your head. The difference between a typical VR HMD and the AR HMD is that a typical VR HMD completely immerses the user in a virtual world, excluding him from the real world. What the user will be seeing is what is being displayed in the monitors of the VR HMD. In the AR HMD we used, there is instead a transparent visor. That means the user can still see straight through the visor. The AR HMD displays virtual objects in the visor with a built-in projector. The software for the AR HMD is based on a window type of system. When the HMD is turned on, the user has the ability to open applications that will appear like floating windows.

To simulate a real application, screenshots of a PDF file were taken, that were then inserted into the AR HMDs gallery application. Upon use, the operator opens the gallery and navigates through the screenshotted instructions. This way, we have a mockup type solution, to simulate a real application. When the gallery is opened, it appears as a floating window, as a part of the user's real world. The user can adjust the size and position of the windows virtually everywhere.

## 3.1 TAM model application

The TAM model was related in all major parts of this study. It was related in the observation guide and results among other parts. One important part where the TAM model was applied is in our analysis. In other words, in the answering of our research question. The evaluation of what method performs better will be based on the two main variables of the TAM model, *Ease of Use* and *Usefulness*. If both instruction methods were on an equal level, we would have to go deeper into the TAM model and take even more variables into account. This would widen the view and possibly find the true superior instruction method. Assuming that AR was the better performing instruction method, it is of interest for Siemens to find out if such technology is ready to be implemented. Therefore, the final variable in the TAM model would come into play, namely *Actual Use*.

The actual usage of the technology will be impacted by the other 4 variables and dictated by the behavioral goal. The value of the *Perceived Usefulness* and *Ease of Use* is the degree to which an individual trusts utilizing the innovation that will upgrade their work performance and that the technology will be free from effort (Davis, 1989).

## 3.2 Data collection

This study was designed with the use of observations and interviews. According to Denscombe (2018), using a *participant observation* generates qualitative data, which is what this study intended to provide. We had chosen *participant observations* as Denscombe (2018) defines them as a discreet method of observing lifestyles, cultures and beliefs. He also explains that a *participant observation* focuses on what is happening and the reason behind it, unlike other observation methods.

The operators that participated in this study were chosen randomly of which were available. This was made possible with the help of our contact person at Siemens. We performed two observations and two interviews per operator. The purpose of the first observation, was to have a base to compare the second observation to. While the first observation was done while the operator received instructions through paper, the second observation was done while the operator was using an AR HMD to receive instructions. Sometimes this order was mixed up, meaning that we let some operators start with paper and other with AR. This was done to eliminate any memorizing of the instructions that might occur when the same task is repeated in a short amount of time.

The interviews were done after each observation, meaning that after the first observation, we followed up with an interview right away. The same thing was done after the second observation, on the same operator.

A *participant observation* is a good method for data collection in "natural" environments while letting the scientist be a part of what is happening. While getting data from one source, we wanted to receive data from another perspective, namely the operators themselves. That was made possible by using *semi-structured interviews*. To keep the answers related to our research question, we wanted a structured method, but still not a method that would be too structured (as a *Structured interview*) to not hinder any respondents from providing valuable data that could potentially arise (Denscombe, 2018).

The interviews and observations provided us with very important information. We used the interviews and the observations as a way to complement each other. In other words, they were both tied and related towards the answering of the research question. Using triangulation ("method combination") provided validation for the collected data, especially if the data corresponds to each other. Schaefer & Alvesson (2020) explained that the use of multiple methods should be used to make theoretical inferences. They mean that interviews should be complemented by observations, surveys, documents, and other methods to triangulate the phenomenon under a study and minimize biases. Schaefer & Alvesson (2020) also mention that for scientists to be really effective for source critique, observations should be related to interview statements. This is because interviews are often much less reliable than they appear. Dukic et al. (2007) performed a similar study to ours. Their study took place in a Volvo facility, where they used both observations and interviews.

Our interviews played a very important role. Not only did they provide validation for the interpretations made on the observation, they also gave answers regarding user acceptance. The interviews allowed us to get “closer” to each operator, where we got a deeper insight on what the operators actually felt about using AR. Given this fact, we could conclude that the interviews served two purposes at the same time.

### 3.2.1 Observation

**Observation guide:**

In order to make relevant interpretations of the observations, we designed an observation guide from all measurable variables in the TAM model. These factors were also used as theme phrases in the result section, as that provides interpreted data and organizing methods that relate to each other.

The following factors are what we focused on during an observation:

- **Completion time (Usefulness)**
  To observe time completion in certain tasks, it would allow us to understand the *Perceived Usefulness* of AR in this context. Davis (1989) describes the *Perceived Usefulness* as "the degree to which a person believes that using a particular system would enhance his or her job performance". Fiorentino et al. (2014), who also used observations in their study, aimed their focus on a similar factor and described how AR can potentially lead to time saving. They explained this by stating that AR has the potential to reduce users’ body movements, cognitive effort and attention switching, and therefore it could lead to faster execution times. Measuring the completion time from the observations would be one factor allowing us to evaluate if AR performed better than paper.

- **Difficulties in accessing, reading and organizing instructions (Ease of Use)**
  Since *Ease of use* is defined as the degree to which a person believes that using a particular system would be free from effort, this factor relies on the perception of the operator. In this case, application of this variable would mean observing how well the operator can access, read and organize his instructions. Uva et al. (2017) also made a similar study and analyzed *Ease of Use* of AR compared to paper by examining difficulties of tasks. However, their results provided quantitative data from questionnaires rather than observations.

- **Ambition and motivation towards tasks (Attitude)**
  According to Davis (1989), *Attitude* is the impression of the technology on a general level. When measuring the ambition and motivation towards the tasks in the observations, we took the *Attitude* variable, from the TAM model, into account.

- **Body language and confidence in tasks (Attitude)**
  According to Selwyn (1997), *Attitude* will affect the preparedness, acceptance and individual behavior towards computer technology, therefore *Attitude* is important to be studied in the use of computer technology.

  PE (perceived enjoyment) as the internal motivation has been studied to discuss how it affects one’s behavior towards technology adoption (Heijden, 2003).

The observation guide factors presented above, are those that we found will aid us in the answering of our research question. Masood & Egger (2020) performed a similar study and looked for similar factors in their observations. This, in turn, played an important role in the development of our observation guide. Fiorentino et al. (2014) also used observations in their study and they aimed their focus at both similar and mutual factors as Masood & Egger (2020). After taking the used TAM variables above and previous studies here into account, the observation guide above was the result.
We choose to document the observations using video recording. Having the observations documented by video gives us the ability to slowly walk through the data and make careful interpretations while using the observation guide. The observations were both documented and interpreted from a third-person perspective. The hardware used to document the observations was an action-cam by the name of GoPro Hero 3. The choice of this device is based on the fact that it is equipped with a "fish eye" lens (widescreen). This means that the Hero 3 has a very wide FOV that provided us with a greater insight of what actually was happening around the operator. This was also necessary, partly due to the relatively large work area where the operator performed his tasks.

While the AR HMD had built-in functionality to record videos from a first-person perspective, this did not work because it dragged down the performance of the HMD. We concluded that it would be unethical to have the operator deal with excessive delay and lag while navigating the system, which in turn affects the performance we are measuring.

As mentioned above, time was measured during all observations. We measured the amount of time it took for individual operators to complete their manufacturing tasks. The manufacturing tasks were identical for both observations (paper and AR). Time is a relevant factor for analyzing the performance between the current method (paper) and AR to receive instructions (Fiorentino et al., 2014). The operators might find it easier, feel better or work more effectively by using AR, but if the completion time increased the user acceptance itself would not be enough to justify that AR performs better compared to paper. This is why time was a relevant factor when evaluating the overall performance of both instruction methods.

### 3.2.2 Interview

The interviews that took place at Siemens were conducted with the aid of a digital recorder. The data from the recordings were later transcribed. The hardware used to document the interview was a mobile phone, a Samsung Galaxy S9. The S9 is equipped with an "interview" mode, where the device records audio from two sources (microphones). One microphone is located on top of the device and one on the bottom. The microphone that was located at the top or bottom of the device was pointed to either the interviewer or the interviewee.

Interviews were not only used to gain insights into the operator's perspective of AR, but also to determine the user acceptance of AR usage. Denscombe (2018) explains that an interview provides data that is more complex and subjective, and that people tend to tell you what they think, which is not always what they do. This told us that words and actions might not always be aligned with each other. To be able to examine the performance of AR as an instruction method, compared to paper instructions, we decided to design two interview guides. The first interview guide (Appendix 5) was based on how the operators perceive the *Ease of Use*, *Usefulness* and *Attitude* towards the current instruction method, namely paper. The second interview guide (Appendix 6) was focused on how the operators perceive the *Ease of Use*, *Usefulness* and *Attitude* of AR as a method for instructions. The guides consisted of general questions that are relevant to our aim and were followed up with questions like: “Explain more?”, “In what way?”, “Why?”. These follow up questions enabled us to gather more detailed answers from the operators. In order to achieve validation, where the data from both the observation and the interviews correspond, we designed the second interview guide (Appendix 6) based on the observation guide.

# 3.3 Method of analysis

According to Backman (2016) any collected research data has to be organized. The purpose of organizing data is to ease the interpreting of data and bring a general structure to it. Backman (2016) points out that organizing data is necessary for the ability to properly answer the presented problem/research question. To organize the data correctly we applied a thematic analysis. Using this method of analysis focuses on examining certain patterns or themes of meaning from the data that had been collected.

Different data had a different type of organizing method applied to it. For instance, all our interviews that were voice recorded, were transcribed. Each transcription is presented in the form of an appendix. Transcribing is necessary to help understand the collected data, as well as making it easier to compare different data to each other (Denscombe, 2018).

When analyzing the observations we focused more on what the operators were doing rather than what they were saying in the interviews, as this is also pointed out by Denscombe (2018). The analysis was built on a thematic description of an operator's behavior.

# 3.4 Ethics

Like all other research work, ethics is of importance, especially if participants are a source of data. As a researcher, we are expected to conduct our work in an ethical way. A direct example of this might be the fact that researchers do not hold any further value than the participants in the study. This means that researchers have no right to perform any action that might harm participants, regardless of how valuable the outcome might be (Denscombe, 2018).

## 3.4.1 The four ethical principles

The following is the four ethical principles forwarded by Denscombe (2018):

**1. Protection of the participants’ interests**

This part ensures the physical and psychological protection of all participants. Researchers must guarantee no harm, both in the short term, as well as in the long run.

**2. Participation must be free of choice and based on consent**

The second principle ensures any participant’s free choice of participation. No participant should ever feel an obligation of participating. This is also applied during data collection, in the middle of an interview, for example.

**3. Researchers should perform their work in an open and honest way, with regard to the study.**
The third principle enforces the “honest” factor on researchers. The third principle makes sure all researchers hold up their “end of the deal”. Researchers are obligated to always be clear when explaining the purpose and what will be done.

**4. Studies should follow national laws**
In the fourth and last principle it is all about obeying the law. This applies to everyone, regardless of role in the research.
For valid application of ethics in a study, participants must be given information and the ability of choice, when it comes to consent and dissent. As mentioned before, it is the researcher’s responsibility to provide all the information and the rights that a participant has. Ethics should not only be applied before a study is made, but also after. Researchers must give great regard when it comes to dealing with any collected data. This is to protect both the integrity and security of a participant/firm that participated in the study (Denscombe, 2018).

## 3.4.2 Informed consent

**Rights for you as a participant**

- Voluntary to participate
- It is your right to regret taking part at any time during the study.
- Your real name is not used, fictitious names will be applied.
- The observation (video recording) and the interview (audio recording) are used for the purpose of drawing a conclusion to our study.
- Video recordings and audio recordings will not be shown to anyone other than us researchers (Ibrahim and William).
- No saved material (video recording and audio recording) will be published anywhere.
- All material will be deleted after completion of the study.

Figure 2. Ethical letter.

The presented above (Fig 2.) is what we call “An ethical letter”, that we designed based on the four ethical principles. This ethical letter was given to all participants well in advance, to study and to properly shape an opinion on the matter. We also let the participants sit down alone and take in the contents of the letter in peace. Before each data collection (observation/interview), consent was requested based on the ethical letter presented to them. This was done after the video/sound recorder was started. This way, the participants' voice that gave consent, would be tied to the same voice providing answers, without compromising the participant’s identity.

## 3.5 Acquiring literature

Literature for this study was mainly obtained from the database *Business Source Premier*. It also occurred that the database *Emerald* was used a few times, but not to the level of Business Source Premier. Before choosing an article, we always tried to narrow the number of results. This was not always the case, since we wanted to avoid missing out on any important research material. The number of results achieved when searching ranged between approximately 20 and 4000. For all the material to remain scientific, we applied certain filters. The main filter used was the “peer-reviewed” filter. We also set the document type to “article”. Before using any collected material, inspection of the articles was made. This was done to ensure that the articles were of a scientific structure.

An example of a complete search phrase would be "Observation study" AND "virtual reality" OR "Augmented Reality” OR "VR" OR "AR". The presented search phrase was used to retrieve scientific material about previous studies that performed observation studies related to the use of AR/VR. That search phrase gave us a total of 64 hits. Another example of a search phrase would be “Qualitative research" AND “interviewing” AND “observation”. This search phrase was used to gain general information about our two methods of data collection as well as qualitative research. This search phrase gave us 100 hits. And the same filters as the previous search was used, namely “peer-reviewed” and “Document type: Article”.

| Recurrent words in our search terms |
|---|
| “Augmented Reality” / “AR” |
| “Virtual Reality” / “VR” |
| “Instruction” |
| “Operator” |
| “Observation study” |
| “Interview” |
| “Implement” / “Implementation” |
| “Technologies” |
| “Manufacturing” |
| “Improve” |
| “Digitization” |
| “Industry 4.0” |
| “Technology Acceptance Model” / “TAM” |

Table 1. Recurrent words in our search terms.

# 4 Result

Since variables from the TAM model were used as guidance (observation guide) to extract important data from our observations, we will also be using these variables as theme phrases when presenting the collected data, as mentioned previously. The collected data from our interviews and observations was categorized under each theme phrase, where it is most relevant. The used theme phrases are found below:

- Ease of Use
- Usefulness
- Attitude

The four observations that were conducted were split into two different processes:
In the first process, the operator has to shape a metal detail using machines. This metal detail is one of many other details that would later be a part of the assembly of the combustion chambers. On the second process, the operator has to weld a small metal piece that would also later be assembled. We will refer to the first process as the "shaping process" and the second one as the "welding process".

The shaping process, where two of our observations were conducted, consisted of two tasks. We will be referring to them as "phase 1" and "phase 2". Phase 1 was a preparation phase. It is the phase where the operator fetched the necessary tools and material to perform phase 2. Phase 2 is the phase where the operator performed the actual manufacturing itself. The operator we observed in this process will be referred to as Operator 1 (OP1).

In the welding process, where the other two observations were conducted, there were not any obvious "phases" in the job. The operator didn't have to set any measurements or fetch certain tools. All of it was already there. Both shaping, cutting and most of all, welding. It all occurred in a nonspecific order. Therefore, we will not be dividing this process into phases. The operator we observed in this process will be referred to as Operator 2 (OP2).

## 4.1 Ease of Use

### 4.1.1 Paper

From our observations we found that the operators often had a limited amount of space near the machine to organize their paper instructions. In these small spaces, instructions would often be stacked on top of each other and more difficult to organize. We also found that the papers could easily get dirty in this type of manufacturing environment. OP1, in his interview, mentioned that some operators would sometimes need to use reading glasses when trying to read the paper instructions. This was mostly due to the fact that the instructions were limited to A4 size paper and because of that the information could be small and difficult to read. OP2 explained that the handling of papers was very cumbersome and took up a lot of space and was often in the way a lot of the time. OP2 also expressed that paper instructions were difficult to read sometimes like OP1 previously mentioned.

The results also indicated difficulties when it came to issues like accessibility. OP1 explained from his interview that he would have accessed a computer and that it might be occupied or that the printer might be out of paper. OP2 also stated that he would have to wait sometimes for an available computer, so he could print out his paper instructions.

### 4.1.2 Augmented Reality

According to OP1, it takes some time to get used to the AR HMD. We could confirm this during his observation. An example of this would be when the participant headed towards his work bench, where his paper instructions usually lie, to realize mid-way that they were in the HMD he was wearing. OP1 spoke about how it got easier to get used to it after ten minutes, but he estimated that it would take a whole day to fully get used to it. OP2 on the other hand, had no issues getting used to the AR HMD at all. He started performing actions that were not explained from us and was always a step ahead.

Generally, from what we could see in the observations, the operators performed their tasks well while using the AR HMD as a source of instructions. Certain tasks that required precision were performed without any issues.

#### 4.1.2.1 Accessibility

Both the observations and the interviews allowed us to get a hold of some important points on accessibility. Something that occurred often, was when OP1 was looking under the visor, instead of through it. We later found out that there was a connection to this, when we interviewed OP1. The operator explained how the visor's brightness was low, or how it could be brighter at least. We also found that the operator actually was looking through the visor at some points while picking tools that proves this not that big of a problem, especially since the operator was looking through it at the same place as when he was not looking through it. This was also confirmed by the operator himself, in the interview. We could not find any obvious connections to this while observing/interviewing OP2 more than that he was actually able to read other paper documents (not related to instructions) while wearing the AR HMD. However, what OP2 could not do was use the AR HMD while welding. OP2 had to take off the AR HMD in order to equip the welding helmet.

We mentioned the issue about the visor and that it is not that big of an issue, however, there are other things we picked up on. Sometimes, we could see OP1 having reduced awareness. An example would be when the operator did not properly place back a tool on the workbench, that almost made it fall on the floor. This could potentially cause damage to it or something else. Sometimes, the operators would have a hard time finding their tools, especially OP1. In the beginning of the observation on OP2, a small interruption happened since OP2 forgot a certain gesture that was needed to navigate the main menu.

Another interesting issue was the fact that OP1 could not navigate the HMD at all with gloves on, while it was the complete opposite for OP2. However, when OP2 was using paper, we could see him taking off his gloves to read through the instructions. What OP1 did most of the time was simply remove the safety gloves to navigate. This poses a safety concern, as the operator could forget to put the gloves back on, before continuing his task. Another interesting thing we could see was that OP2 could navigate in the AR HMD, not only with gloves on, but while holding tools in the same hand that is used to navigate. Navigation sometimes happened unintentionally while OP2 was working. In other words, the AR HMD sometimes interpreted the operator's actions as navigation gestures. OP2 suggested a “lock-mode” to be implemented in the HMD. A feature that would lock the interface of the HMD and not allow any gesture inputs.

The AR HMD was not very easily used when wearing normal glasses according to OP2. In this case, it is not an issue. People with reduced sight (operators who wear glasses), could use the AR HMD without glasses. When using paper, glasses would be needed all the time, but when using the AR HMD everything was clear. OP1 explains that you could simply zoom in (or out) if needed. Another positive thing is that the instructions would always “be with you”, this is a mutual opinion between OP1 and OP2. With that said, the operators mean that the instructions are always in the HMD and that you do not have to walk over to the workbench to check what the next task is.

#### 4.1.2.2 Hardware Ergonomics and Spatial Comfort

The AR HMD, ergonomics wise, was perceived as pretty good. The operators equipped themselves with the HMD easily. Though we could see, while performing the observations, that the operators made some minor adjustments to the AR HMD while wearing it. For OP2, this occurred multiple times. Later in the interviews, OP2, who made excessive amounts of adjustments, still stated that he had to make excessive adjustments, trying to increase visibility. OP1 who made minor adjustments, stated in his interview that the HMD had good ergonomics and adjustment possibilities. OP2 strengthened his statement by comparing the weight of the AR HMD to the welding helmets used at Siemens. The AR HMD was lighter than the welding helmet, according to the operator. The operators explained that for a short amount of time, it would mean no bigger issue, but for a longer duration it would most likely cause fatigue. OP2 explained that he was worried about leaning while wearing the AR HMD, because he feared it might fall off.

### 4.1.3 Confidence

#### 4.1.3.1 Paper

The first thing we saw when we observed OP1 using papers, was that he knew right away how to organize his instructions (papers). It seemed like it is a thing the operators do all the time before starting on their tasks. Even though OP1 organized his instructions, we could not see how he was dependent on them while working. Sometimes he started on new tasks, without checking the instructions. The same thing can be said about the tools and measurements. It is like they are memorized.

Another thing we could see regarding both operators, was that there was no “tense” situation while working. The operators made jokes and held conversations with their co-workers. Furthermore, factors that proved confidence would be that we could see OP1 sometimes reaching for his tools without even looking in that general direction. At one point, the operator switched tools and suddenly stopped. It was at this moment we could see that OP1 became unsure and actually checked the instructions, proving the instructions were necessary. Most of what we saw in the observation of OP1, was later confirmed in the interview. OP1 explained how he is confident with the current way of working with paper instructions, as he stated, “I have been doing this for many years”. When we asked the operator if such confidence comes with time, the operator agreed. Most of this is the case for OP2, as we got similar responses when asked the same questions.

#### 4.1.3.2 Augmented Reality

Generally, while it took OP1 some time getting comfortable moving freely, OP2 immediately developed a sense of confidence for the AR HMD, which allowed him to move freely right away. When an operator got comfortable in wearing the AR HMD, we could see how he began to move back and forth without any limitations. This could be between the operator's machine and his work bench to switch tools, for example. OP1 and OP2 performed the exact same tasks as done when using paper, really well. In other words, we could not see the AR HMD affecting the outcome of the task. While observing OP2, we saw that he froze for a longer time in the beginning, but that was only in the beginning, right after equipping the HMD.

Something that we want to point out about both operators is that they were still independent and completed their tasks without needing any extra help or aid from co-workers. Fetching tools was not an issue and nothing hindered them from having conversations with their co-workers, even while using the AR HMD. This was interesting to see, considering that both do not have any past experience with AR at all, according to what they said in the interview.

## 4.2 Usefulness

### 4.2.1 Paper

Both OP1 and OP2 stated that instructions would now and again be updated from the main office. This would lead to operators having to constantly check if new updates had occurred, meaning that old papers instructions would not meet the latest ISO requirements and as a result of this would have to be thrown away. Therefore, this would result in new papers having to be printed. OP2 said sometimes the instructions were not always updated or information was missing so he would have to go back to the computer and print out even more paper. OP2 mentioned that the papers were burnable and that they had to be kept away from certain machines and welding equipment, as they had certain rules of how far away the papers had to be kept. OP2 also mentioned how the *Usefulness* of paper was limited to just text and images. He explained this by stating "Some things are hard to explain in text. For example, when I'm welding it's very hard to understand how welding works and to explain this in text is very difficult. I could describe it as trying to recreate Picasso's paintings with the help of text, So it's not always so easy".

### 4.2.2 Augmented Reality

Both operators had something in common and that is the general understanding of the instructions, as both operators knew what to fetch and how to organize it. When OP2 took a look at his instructions, it seemed like he understood them right away, in terms of speed. The same could be said about OP1, but he did not use the instructions as much as OP2. OP2 sometimes wrote on papers (taking notes), and this happened without any issues while still wearing the AR HMD. OP2 had to take on/off the AR HMD each time he wanted to wear the welding helmet, which is something that happens multiple times during a task. OP2 complained about the lack of adjustment possibilities. He wanted to be able to twist the instruction window on a certain axis that was not possible for the kind of hardware this study used. Another very interesting thing we found out when interviewing OP2, was that the AR HMD sends out frequencies that disturb the welding helmet. What both operators appreciated a lot was the fact that you had the option to place the instructions windows virtually wherever you want.

### 4.2.3 Time

Since this study had chosen to remain qualitative, we did not dive too deep into numbers. Time was briefly used as was relevant for a study that measures performance, according to (Fiorentino et al., 2014) & (Uva et al., 2017).

The results from the interviews showed that time was mentioned several times while we were discussing Paper instructions. Both OP1 and OP2 explained that they had to wait for computers to become available because they were sometimes occupied by other operators. OP2 also explained that the printers would be low on ink or sometimes out of paper. Therefore, this leads to more waiting time. When OP2 was asked about his thoughts and views on paper instructions he mentioned overall that it takes up a lot of time when using paper.

To evaluate the time aspect, we compared the differences in time completion between paper instructions and AR instructions. They are presented as charts below:

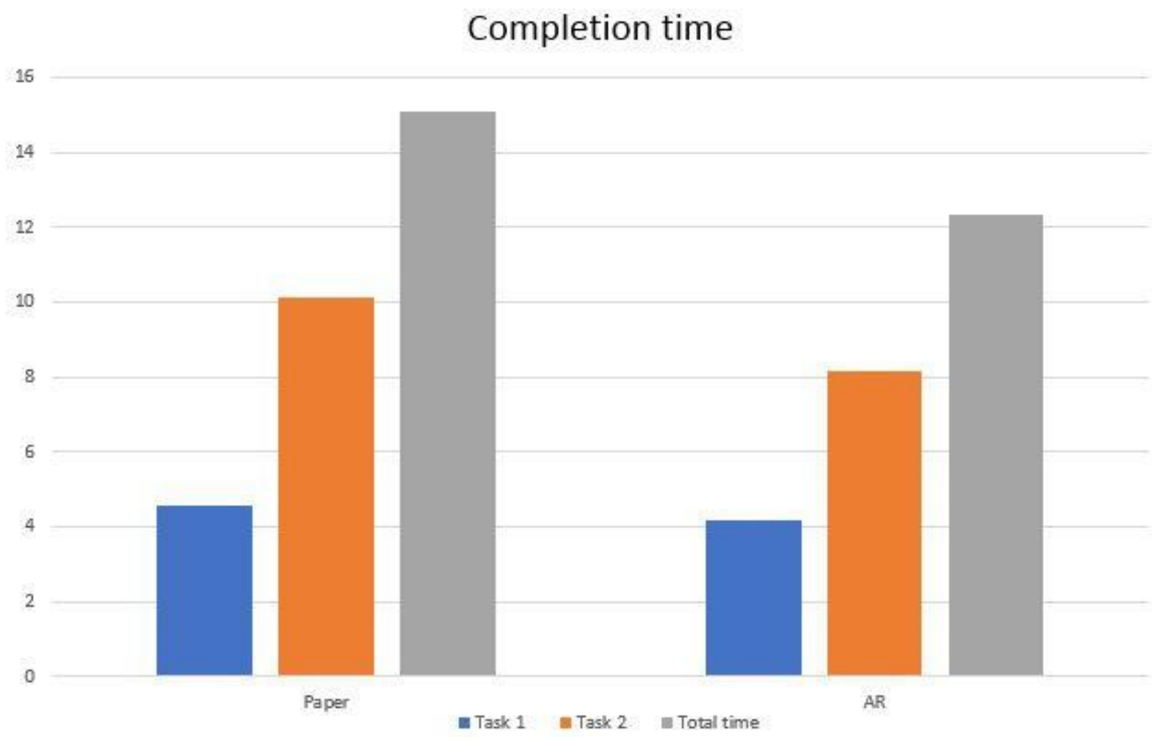


Figure 3. Completion time, Observation, OP1. UNIT: Minutes.

The completion time was measured for each phase in the first process and the total time of completion for the whole procedure. In the preparation phase (Task 1) the results showed that AR decreased the preparation time compared with the paper instructions. For the actual “shaping” phase (Task 2) the data from our observation also confirmed that the time decreased when using AR compared to paper.

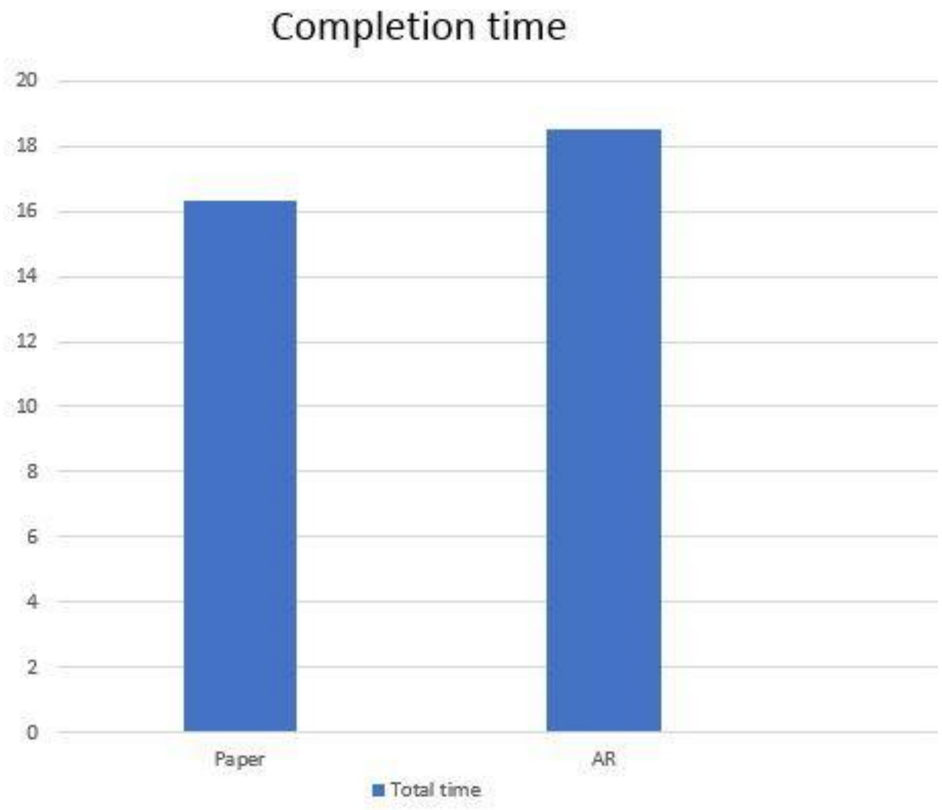


Figure 4. Completion time, Observation, OP2. UNIT: Minutes.

Unlike the shaping process, there was only one continuous task. In the welding process, there were not any obvious divisions in the tasks. In other words, there was not a “preparation” phase or an “actual work” phase. Therefore, in the welding process, the completion time was an overall measurement.

# 4.3 Attitude

## 4.3.1 Body language

### 4.3.1.1 Paper

When observing OP1 while he was using paper, his body language was very relaxed. He moved around slowly, at his own pace. When he needed to be certain of details, he leaned forward to inspect. Examples would be when choosing tools or checking the instructions. We could sometimes see OP1 hesitate, where we interpret it as insecurity in needing to check instructions or not. Sometimes, OP1 grabs tools, he gets insecure if it is the right choice and proceeds to check instructions. OP2 had a regular body language, not too fast or too slow. What could be said about OP2’s body language is that he was certain in every move he made.

### 4.3.1.2 Augmented Reality

When OP1 was using the AR HMD, we noticed confidence in the body language as the operator was navigating in the HMD. In the beginning, he froze on his spot for a longer time, while getting started with the AR HMD. This was also the case for OP2. What was positive though, was that they were standing in a normal, upright position. Both the operators did things like putting on their gloves while checking the instructions for the next task, which indicates a relaxed mindset towards the use of the AR HMD. Another thing we could see on both operators was that after spending some time with the AR HMD, they grew confident and determined. OP1, for example, started to pick tools without looking towards their location. OP2 started to navigate in the HMD while holding tools in the same hand, as mentioned earlier.

### 4.3.2 Ambition

While OP1 did not seem very “tense” and motivated, it was the complete opposite for OP2. The outcome of both processes was still as expected, completion was achieved without issues. At certain points, where attention to detail mattered, we could see how OP1 increased his focus while checking the instructions for numbers or measurements. OP1 actively moved around while interacting with his work environment. OP2 did not check his papers so often and was more dissatisfied with paper instructions. When OP2 used the AR HMD, he started to inspect the instructions right away and was very focused and also paid close attention. We also noticed that he was actively interacting with the AR HMD. When asked about his ambition towards AR he was very positive. One reason being that he is used to wearing safety glasses and that AR HMD provides this safety aspect plus additional benefits. But something that kept both operators slightly worried was the fact that the industry is a harsh environment where equipment like the AR HMD could easily get damaged if not taken care of properly.

### 4.3.3 Mindset

While interviewing OP1, we found that he was okay with today's way of working (paper as an instruction method). OP2 was completely against it. What they both had in common was the opinion about the excessive amount of paperwork and the responsibilities (computers, printing, ink etc.) that follow. Both operators made it clear that they would rather get rid of papers.

When asked about AR, “fun” and “interesting” were some of the answers we got from the operators. The operators were very impressed with using AR in their work. They were open for changes, if it is an improvement. “Changes”, in this context, would mean digitalization. What the operators would appreciate, was if more information could be available, rather than just the instructions that were displayed. They proposed a software integration that would let them control some of the measurements in their work. They also expressed interest in having the AR HMD present live data. When we asked the operators if they could accept any other technology such as a smart tablet, instead of AR, they said that it could work. At the same time, they warned of how not everything could work, since a production environment could be harsh. Overall the operators believe Siemens would be positive towards new and useful technologies, such as AR.

# 5 Analysis

## 5.1 Getting started

We believe that a general conclusion would be that whatever it is you are working with, you will get used to it over time. In this case, it is paper and AR. Taking the results of our interviews into account, you will realize very fast that the operators clearly would appreciate a change. The operators have worked with paper for many years. They are very used to working with papers, even though they might not like it, and they are very confident in this way of working. In the case of AR, you could ask yourself "Why wouldn't it be the same?". Both operators stated that it would not take more than a day to get used to AR. If AR was used for a month, little to no operators would have any issues, we believe.

## 5.2 General difficulties

While analyzing the results it became clear that using paper had a few difficulties. But AR did not get away without difficulties either. From what we noticed and what the operators explained was that it took a bit of time getting used to navigating the AR HMD. This is mainly due to the fact that you have to be more technical or have very good computer knowledge. The operators generally had no larger difficulties positioning (virtually) the AR instructions, although they did point out that they were not able to twist the instructions in a certain axis, laying the paper down on a flat surface, for example. Conclusions provided by Uva et al. (2017) show that experienced maintenance operators become used to the procedures without the support of instructions. This told us that minor issues like the ones presented above will not be of a bigger concern, as the operators eventually might find their way through working with the instructions and become less dependent on them.

Sometimes the operators would forget certain gestures that were used to navigate the AR HMD. This is very important, since it could be dangerous if it occurred in the middle of a task, where the operator would need quick access to his instructions. Findings provided by Uva et al. (2017) show that even the most experienced operators could work on many different versions of one product. Uva et al. (2017) further state that the operator has a hard time memorizing all the procedures which shows the dependency of instructions. Another issue this brings, is the amount of actions and procedures that an operator needs to memorize. If the operators already suffer from not memorizing necessary basic information, it could worsen the situation by adding more responsibilities, such as memorizing AR HMD gestures.

When using paper, after each task in a process is done, the instructions for it have to be disposed of. Not to mention the physical space the paper takes up, which could hinder the work of the operators, as space is important for tools and materials. What Ong et al. (2008) brought up regarding paper, was that if there is excessive involvement with it, valuable time will be lost to it. Ong et al. (2008) also explain how excessive manual work, that being the management of paper, may lead to reduced productivity. Instructions in a paper format are not on one single paper. If there are seven steps for the process, there will be 7 pages of physical paper. Where if AR would be used, it would all be digital and the risk of losing any instructions is minimized. This is also a very good factor for environmental causes and decreased paper usage.

Before getting access to paper instructions, they have to be printed, where other responsibilities follow, such as keeping track of ink levels and the quantity of papers. Before the papers are printed, they need to be in a certain digital format. Excessive manual work, such as the mentioned here, could lead to increased errors, as there are now many factors to keep track of, according to Ong et al. (2008).

There are other issues with papers and one of them is the need to always keep track of paper's position while working. The reason for that is because there are certain rules of the distance the papers have to be kept at, while welding for example. AR solves this issue as Ong et al. (2008) explained how the information is always in the operators FOV. This corresponds exactly to what the operators in this study appreciated. They explained it as "the information is always with you". The downside with AR would be the fact that it is battery driven. The AR HMD needs to be charged and for that, the operators will need to keep track of battery levels as well as plan their usage, which is indirectly manual work.

Moving on with further difficulties, there is the visor clearance in the AR HMD. There is still a visor in front of the user's eyes, which affects the vision of the user, even if it might be minimal, it is still something to consider. What Fiorentino et al. (2014) concluded in their study was that the visibility of their AR HMD was not good enough for it to be accepted by the users. In our case, we had only one complaint from an operator, who experienced the visibility not to be the greatest. Though, he explained that it was not a big problem. This factor is not only important for the comforts of the operators, but also for their safety. Low visibility could lead to the operator having a low situational awareness of his physical environment. Speaking from common sense, decreased awareness is dangerous, especially if it is in a production environment, as there are many elements where an operator could harm himself. According to the interview with OP2, the AR HMD sent disturbing frequencies that affected the operator's welding helmet. The operator not seeing properly while welding could, as awareness decreased, lead to hazardous and frustrating consequences. The disturbances could be solved by turning off the HMD, but since taking on and off the HMD multiple times in a short amount of time, it would make it impractical.

## 5.3 Accessibility

There are differences between AR and paper where one is the superior option in terms of accessibility. First of all, when it comes to paper, the interviews showed that the instructions sometimes are difficult to both read and understand. In AR, that is not the case, according to OP1, since they have the ability to zoom in/out in the instructions. Masood & Egger (2020) found that one of the biggest success factors for AR is the visibility of the information. This perfectly relates to what OP1 said about the visibility of information in the AR HMD he tested. OP1 wears glasses and needs them, especially when reading off physical papers. According to OP1, he had no issues reading the instructions whatsoever, namely because of the ability to zoom in/out.

When it comes to the handling of paper, there are difficulties of handling them with gloves, as the papers are very light and thin. The "gloves issue" exists when it comes to AR too. This issue is not consistent, as one operator had absolutely no issues while navigating the AR HMD with his gloves on, while the other one had to take them off every time. This proves inconsistency for the AR HMD, which goes against one of Masood & Egger (2020) success factors, usability of the user interface. Since paper has been used for a long time, the operators grow used to handling papers, even with gloves on. Discussing the fact that navigating in the AR HMD with gloves is inconsistent, it is worth mentioning that it most likely depends on environmental factors such as light conditions, which could very well be the reason for one of the operators failure to navigate with gloves on. This does not provide reason to ignore the inconsistencies of navigating, as the AR HMD should have been equipped with more advanced sensors. What further supports our claim, is the fact that the sensors in the AR HMD sometimes picked up on the movement of the operator's hands while working and interpreted them as gestures for navigation. Though, a certain level of understanding should be kept towards this subject, as Ong et al. (2008) came to the conclusion that AR applications in manufacturing environments are not always accurate.

In this section, accessibility flaws of both instruction methods have been brought up. It might sound like paper is the superior option to AR when it comes to accessibility, which it might be. The reason for the inconsistencies in the gesture interpretations might be hardware issues, but it might very well be human factors too. We cannot forget the fact that these are results of one day of usage per operator. The same way the operators grow used to handling papers, they can get used to and develop a better understanding of the presented technology, that is if the issue lies within the user. This will then lead to them being able to work their way around any limiting factors in the AR HMD. Fiorentino et al. (2014) concluded that with visual instructions the organization of information is clearer. With that said, we believe AR to be the superior option when it comes to accessibility. Mostly because the accessibility in reading and understanding instructions is better, but also because the navigating issues might very well be relative, as well as worked around by training.

## 5.4 Usefulness

In terms of how useful papers are, there are both previously mentioned factors and non-mentioned factors. What has been mentioned before is how there is a lot of manual work. The operators have to constantly make sure that all the information on the papers are correct. The slightest mistake on a paper makes it invalid, which results in the paper having to be thrown away. This makes paper a sensitive method to provide instructions. Gattullo et al. (2019) concluded that it is difficult to update paper which aligns with the same problems as ours. In our case, that makes papers useless. The result of papers being invalid is that they will be thrown away, which is not good for the environment. The papers are also flammable, which is not optimal in a production environment as it is hazardous. There are certain rules of how the treatment and usage of paper should happen. As an example, papers cannot be within two meters while welding. The text, or rather the language, is not easy to understand, according to OP2 in an interview. Pictures in the instructions that are printed are in black and white, where it is fully colored when displayed in the AR HMD. This makes it more useful as the operator can identify important details of what is expected on the product being worked on. This corresponds to what have been proven by Gattullo et al. (2019). They claim that AR can reduce the cognitive load when using technical documentation.

One of the main factors that make AR useful compared to paper is the fact the operators were able to place their instructions wherever they liked or preferred. If the navigation by gestures does not work, there is the ability to talk to the AR HMD, as it supports voice commands. This is not the main way of navigation, but it is very well worth mentioning. Although Masood & Egger (2020) did bring up the issue that voice recognition is problematic in factory environments, as other sounds and noises might interfere. As previously mentioned, the AR HMD is battery driven, which limits the flexibility of the usage. The operator has to plan the usage and keep track of the battery level. The point here is, when it comes to *Usefulness*, this is a negative factor.

## 5.5 Time

When analyzing the time aspect, AR and Paper performed quite similarly. In fact, when using AR, the time decreased slightly compared to paper and in the first observation the operator performed both tasks faster when using AR. The results from this study were also similar to what Fiorentino et al. (2014) provided. When AR was used, the completion time was reduced. In our case, we cannot clearly come to the conclusion of which instruction method performed the best in terms of time completion, as there were no major or significant differences. However, if the completion times would have differed a lot then it would have been more interesting for the conclusion of this study as this could have affected the actual *Usefulness* of AR compared to paper. We also need to take into account that this was the first time for both operators to use AR. We want to believe that the results would differ after a week, or even a month's usage.

## 5.6 User acceptance

Since AR is a new technology, it will go through a lot of criticism before being accepted. There will be many questions regarding how well it will work as a replacement for something we have been using for a long time, which is paper. As mentioned previously, Industry 4.0 moves towards digitalization (Ardito et al., 2019). According to Gattullo et al. (2019) exploiting AR is also a valid way to create technical documentation compliant to Industry 4.0, since it is one of the nine enabling technologies. That implies moving on from the use of paper, to something more digital, like AR. Although the operators were generally satisfied with the paper instruction method, they were open to change, if better solutions became available. Both operators made it clear that they would have no problems getting rid of papers if better solutions became available. OP2 actually stated that he was completely against the idea of using paper. When asked about their views towards using AR instead of paper they had a really positive mindset. Both operators expressed how AR was interesting and fun. They expressed how they would be positive towards technologies such as AR. However, OP1 and OP2 did express some improvements that could be made. They proposed a software integration that would let them control some of the measurements in their work and have information presented with live data. OP1 was also skeptical to durability of AR devices in a harsh production environment. OP2 hinted at the possibility of being able to use the AR HMD while wearing a welding helmet.

## 5.7 Summary

As from what was brought up in the analysis, we feel like AR is the superior option in terms of what has been brought up, as we experience that paper brings more difficulties than AR does. AR does not escape free of difficulties, but we believe that most of the difficulties are solved by experience and time. When it comes to forgetting gestures, the best thing would simply be testing it for a week or two to find out if these are actual problems. Forgetting gestures will not be an issue since that will be a part of an operator's muscle memory, we believe. As for visor clearance and awareness, the operator might develop a good sense of his surroundings after some time. In other words, there is a possibility that the operators can adapt to their environment, even with the AR HMD being worn. This is also something that should be tested first, as one day of use might not be enough. If AR were to be implemented as a replacement for paper, all the manual paperwork will be written off. This would mean that all the space that the printers and computers take up could be used for something else. Certain issues with AR, such as the AR HMD sending disturbing frequencies will remain, but workarounds are possible. Just like the operators have to deal with issues regarding paper. Instead of turning off the HMD, it could be taken out of that room temporarily until the welding is over, for example.

# 6 Discussion

This study has studied the difference in performance between paper and AR as an instruction method in a production environment at Siemens. The study was carried out on two different processes where both observations and interviews were used. By using multiple data collection methods, we applied triangulation (method combination) which in turn provided validity for the collected data. We could see how the collected data corresponded with each other which strengthened our findings. The results of this study did not only provide information on what instruction method was the superior choice, it also showed that AR technology has a lot of potential in areas it can be used in.

## 6.1 Method discussion

This study was of qualitative work. Having it any other way, that being quantitative, would not be optimal in our case, as we are performing the study for a specific company. De Souza Cardoso et al. (2020) sought to generalize subjects about AR, therefore, their choice of research method was of quantitative elements. On the other hand, Masood & Eggers (2020) performed a qualitative study, by using experiments.

On the choice of data collection methods, we think that it provided good assistance in gathering the necessary data to answer our research question. Interviews alone, would not bring the same validity as interviews and observations combined. It would be the same if observations were used alone, because this method would not allow us to come to any conclusions regarding the user's acceptance from the operators.

To find out if paper or AR performed better, we put a lot focus on the results from the observations. Interviews mostly help with ideas and user acceptance. What interviews sometimes helped us with, is confirmation of certain things we interpreted from the observations. When we saw something we thought was of importance from the observations, we later got it confirmed from what that operator said in the interview. That way, the interpretations we made became more valid, as the operator himself said the same thing.

As regards to the theory that was used for this study, it was very useful for coming to a conclusion of how AR performed as an instruction method at Siemens. The theory also allowed us to identify the operators *Attitude*s and *Behavioral Intentions* for this new technology in a manufacturing environment. Although there are some people who have criticized the use of the TAM model, Lunceford (2009) argues that the framework of perceived usefulness and *Ease of Use* overlooks other issues, such as cost and structural imperatives that force users into adopting the technology. In our case, that means that we cannot take into account costs to implement any hardware or technology. We can only base our conclusions on the performance and the user acceptance. There are multiple versions of TAM. What made the choice of this version of TAM relevant to us, is the fact that it is the simplest version of them all. It does not perform any specializations in specific areas. In other words, it is a very general theory. What also supported our choice is the fact that the two main variables, *Ease of Use* and *Usefulness* are aimed exactly at what this study aims to study. The performance (*Usefulness*) and the user acceptance (*Ease of Use*).

# 6.2 Evaluation of ARs performance

Davis (1989) describes that new Information technologies have the potential to boost the performance of workers. But these performance gains are often obstructed by the users' unwillingness to use and accept available systems. By applying the TAM model in this study, it provided us with a framework to understand the *Ease of Use* and *Usefulness* of AR as a new technology for providing instructions for the operators at Siemens. To find out if AR performed better than paper both the *Ease of Use* and the usefulness of the system would have to be better than those of paper.

## 6.2.1 Ease of Use

From analyzing the results, it showed that difficulties with the *Ease of Use* of AR was slightly less than that of paper and therefore easier to use overall. The main difficulties with paper was getting access to them as they have to be printed out every time. Also, the operators had to keep track of the quantity of papers and occasionally keep an eye on the ink levels, as mentioned previously. Papers were more difficult to sort and organize and took up more physical space. From our findings it became clear that the AR instructions are easier to read as this was mainly due to the zooming possibilities. Which again, aligns with what Masood & Egger (2020) provided regarding visibility of information. One of the main difficulties we found with AR was that the operators sometimes forgot some of the gestures that were needed to navigate the AR HMD. Just as Uva et al. (2017) concluded, operators in manufacturing already have a hard time remembering all their procedures. But we believe that these difficulties will be solved over time. Although there is one small issue for the AR HMD and that is the battery life. This needs to be fixed to improve the *Ease of Use*. Hardware ergonomics is also something we took into consideration when looking at the *Ease of Use* of the AR HMD, as De Souza Cardoso et al. (2020) explained that this could cause fatigue. From the interviews the operators explained that they had no major comfort issues or complaints while using the AR HMD. This can be discussed because they only wore it approximately 15 minutes at a time. Although their opinions might have differed if they wore it for many hours or a whole day. However, we believe that this will not be a major issue as the ergonomics are expected to improve in the future and no longer be a physical and obstructive burden to the users. According to Ong et al. (2008), the hardware of AR technology will become smaller and lighter.

### 6.2.2 Usefulness

Overall the *Usefulness* of AR was perceived as better than paper. The findings showed that operators had the flexibility with AR to place their instructions where they wanted, thus being able to perform tasks without having to hold the instructions. In turn, this allows them to have both hands available. This finding was similar to those of De Souza Cardoso et al. (2020). They came to the conclusion that reasons why AR HMDs tend to be used in production environments, is the mobility that they afford to users during the manufacturing process. The paper instructions were less useful due to the fact that they could not be updated and would have to be thrown away after every use. AR was also more useful than paper because it allows more options for displaying and receiving instructions than paper. Paper was limited to just text and pictures, whereas AR can provide instructions in the form of videos and visual objects. This in turn opens up huge possibilities in terms of *Usefulness* for AR. In terms of completion time, AR and paper performed similarly in our observations. But as mentioned previously, we believe that the more time the operators spend using the AR HMD, the completion time of tasks will become faster. However, with that stated, AR technologies are still developing and have the potential to become even more efficient with future upgrades to the hardware and software. It would be interesting to see how a HoloLens application, specially designed and customized for Siemens could impact the time factor and the general *Usefulness*. As Ong et al. (2008) state, AR applications have to be fast and reliable to use. This is important to take into account when designing future AR systems. The application also needs to have efficient and suitable user interface that can be conveniently used to interact.

## 6.3 User acceptance

One of the biggest challenges from previous studies was the user acceptance. Overcoming this challenge would mean large success but failing to do so would be a bigger problem, according to Masood & Egger (2020). Thus, we have to keep in mind that not all operators may have a positive attitude towards using AR. However, while analyzing the results from this study it became clear that the operators had a positive *Attitude* towards AR. We believe that one of the main reasons behind this is due to the “fun” factor the operators experienced and the fact that AR is an interesting technology in itself. The operators made it clear that they would not have a problem with giving up papers. One of the operators was totally against the use of paper, OP2 to be specific. This was partly because of how cumbersome the papers were when it came to providing instructions. But this could also be due to how society causes us to have a guilty conscience when using unnecessary amounts of paper and that using too much paper is bad for the ecosystem. However, we understand that the AR HMD still needs improvements for operators to fully commit to using it, instead of paper. As mentioned previously, this could be made possible with a HoloLens application that was specially designed for their type of work and needs. We find this solution obvious as we do not recommend the mock-up solution with pictures used in this study. We believe that this in turn would increase their *Actual Behavioral Intentions* for using AR as a replacement to paper instructions. Just because people have a positive attitude towards a new innovation, does not always mean that they intend to use it. As Davis (1989) explains, the *Behavioral Intention* in the TAM model, is the factor which actually leads people to use the technology.

## 6.4 Ideas and potential of AR

De Souza Cardoso et al. (2020) express that the technology used (AR) acts as a critical factor for improvement in the process flexibility. In our case, that would mean using the AR HMD to its maximum potential and that involves developing customized applications that are integrated to a company's central system, for example. De Souza Cardoso et al. (2020) mean that factors that lead to process flexibility also lead to company success. Therefore, there are ideas presented below, regarding the usage and the potential for the AR HMD we used in this study:

An idea came from OP1. One of his complaints about the AR HMD was the brightness of the visor, and he suggested that there could be an option to adjust it. We cannot say for sure if the low brightness depends on the physical material of the visor or if it is the visor's display brightness setting that is “hard coded” from the factory, with no possibility for adjustment. We can see this as a very important feature as it could be potentially dangerous for the operator to not have the optimal vision while performing his tasks, as mentioned earlier. The operators stated that it was not the biggest issue, but only a thing worth mentioning. We still see this as an issue that should be taken seriously.

Another feature that was proposed from OP2 was a “lock mode” for the AR HMD. In other words, a feature that locks the interface of the AR HMD, so that no input should be able to be made. As OP2 explained, sometimes the AR HMD interpreted his work actions as gestures to navigate the menus. We can see this causing unreliability and inconsistency. As of the current way the operator received instructions, it would not be a bigger issue if something would happen accidently, as it is only instructions in a picture format. If the AR HMD would feature a real solution, with live integration and updates it would be a serious issue. In such cases, where permanent action could be made, this would be a grander issue as the AR HMD now could misinterpret the operator’s actions and cause destruction of important data, for example.

When analyzing our results further, we found that there were excessive transitions between the welding helmet and the AR HMD, as the operator could not wear both at the same time. We saw this as a factor that dragged down the practicality. The operator had something else in mind. OP2 suggested that AR could be integrated into the welding helmet, or vice versa. If the AR HMD would be made to work as a welding helmet, this issue would be solved.

After this study was done, the operators were left with ideas and knowledge about the possibilities the AR HMD had; all from usage in other areas than just an instruction method, to advanced integrations to central systems, and to view even more important data. Another suggestion was live updates in the AR HMD, where the AR HMD would update the instructions and statuses in real-time. Though, according to Ong et al. (2008), in order for this to be adopted in manufacturing, it has to be a fast and stable Internet-based collaborative AR system for manufacturing activities. It is important, as it will be a challenge to meet the highly competitive business and manufacturing environment. If such a system was to be developed, each operator would get their own account, for example, where they could get authenticated through eye scanning. This enables a personalized view for each operator when he logs in to the system.

# 6.5 Future studies

Since the results of this study showed that there is a lot of potential in the AR technology, we can without a doubt say that there are many possibilities for future studies. In our case, what would be interesting, would be to see a more realistic and detailed approach of our version of this study. If Siemens were to follow what Ong et al. (2008) provide regarding AR applications, if a fast and stable internet-based solution that integrates to Siemens central system were to be developed, you could get more “realistic” results, as that would be how they would work if AR were to be implemented. What would also be interesting is to heavily increase the resources of the study so the majority of the company could participate. That would reveal the true *Attitude* of the operators, towards AR technology. We also think that before companies will put their trust in such technologies, there needs to be more studies and general information about AR. With that being said, we think that this is an actual research topic at this point in time.

# 7 Conclusions

How well does Augmented Reality technology perform compared to physical papers as an instruction method for operators in a production environment? Based on the results from the observations and the interviews, we found that AR is definitely a suitable replacement to paper as an instruction method. AR was better when it came to *Ease of Use*. This was mainly because of the accessibility it provided and that the handling of paper instructions was more cumbersome. AR allowed for easier ability to take in and understand instructions, regardless if an operator has reduced sight ability or not. This is thanks to the built-in features such as zooming in/out. When it comes to *Usefulness*, AR was superior to paper, not only because the performance was better, but also because the possibilities and the potential it provides. What the operators appreciated the most was the flexibility and mobility the AR HMD offered. Not only could the operators position their instructions virtually everywhere, they could also move around in their workspace where the instructions would still be with them. Another important problem that AR solves is manual work, since paper contributes with many responsibilities when it comes to printing and managing paper in general. The user acceptance of this technology is still not justified, although the operators had a positive *Attitude* towards the use of AR technology. The *Behavioral Intentions* for the *Actual Use* of AR are still unclear, and this will need to be studied more in the future.

Now that we know which method was the superior option for instructions, it might be of interest to know if AR technology can be adopted by Siemens. The answer is no, at least that is what we recommend. Even though AR fulfills *Ease of Use* and *Usefulness*, we feel like that is not enough. AR should not be adopted because it does not fulfill *Actual Use*. Therefore, we can conclude that AR performed better as a method of instruction, but we do not recommend it being adopted by Siemens currently, at this moment in time.

# References

Agostini, L. and Nosella, A., 2019. The adoption of Industry 4.0 technologies in SMEs: results of an international study. Management Decision, 58(4), pp.625-643.

Ardito, L., Petruzzelli, A., Panniello, U. and Garavelli, A., 2019. Towards Industry 4.0. Business Process Management Journal, 25(2), pp.323-346.

Aurich, J. C., Ostermayer, D. and Wagenknecht, C. H. (2009) 'Improvement of manufacturing processes with virtual reality-based CIP workshops', International Journal of Production Research, 47(19), pp. 5297–5309. doi: 10.1080/00207540701816569.

Dangelmaier, W. et al. (2005) 'Virtual and augmented reality support for discrete manufacturing system simulation', Computers in Industry, 56(4), pp. 371–383. doi: 10.1016/j.compind.2005.01.007.

Davis, F., (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly, 13(3), p.319.

De Souza Cardoso, L. F., Mariano, F. C. M. Q. and Zorzal, E. R. (2020) 'A survey of industrial augmented reality', Computers & Industrial Engineering, 139, p. N.PAG. doi: 10.1016/j.cie.2019.106159.

Denscombe, M., 2018. Forskningshandboken, för småskaliga forskningsprojekt inom samhällsvetenskaperna. 4:2 red. Lund: Studentlitteratur.

Dukic, T., Rönnäng, M. and Christmansson, M. (2007) 'Evaluation of ergonomics in a virtual manufacturing process', Journal of Engineering Design, 18(2), pp. 125–137. doi: 10.1080/09544820600675925.

Fast-Berglund. Å, Gong. L, Li. D. Testing and validating Extended Reality (xR) technologies in manufacturing' (2018) Stena Industry Innovation Lab at Chalmers - SII-Lab Nationell Testbädd Smart Produktion - huvudprojekt Procedia Manufacturing, p. 31. doi: 10.1016/j.promfg.2018.06.054.

Fiorentino, M. et al. (2014) 'Augmented reality on large screen for interactive maintenance instructions', Computers in Industry, 65(2), pp. 270–278. doi: 10.1016/j.compind.2013.11.004.

Gattullo, M. et al. (2019) 'Towards augmented reality manuals for industry 4.0: A methodology', Robotics & Computer-Integrated Manufacturing, 56, pp. 276–286. doi: 10.1016/j.rcim.2018.10.001.

Lunceford, Brett. (2009). Reconsidering Technology Adoption and Resistance: Observations of a Semi-Luddite. Explorations in Media Ecology. 8. 29-48.

Manis, K. T. and Choi, D. (2019) 'The virtual reality hardware acceptance model (VR-HAM): Extending and individuating the technology acceptance model (TAM) for virtual reality hardware', Journal of Business Research, 100, pp. 503–513. doi: 10.1016/j.jbusres.2018.10.021.

Masood, T. and Egger, J. (2020) 'Adopting augmented reality in the age of industrial digitalisation', Computers in Industry, 115, p. N.PAG. doi: 10.1016/j.compind.2019.07.002.

Ong, S. K., Yuan, M. L. and Nee, A. Y. C. (2008) 'Augmented reality applications in manufacturing: a survey', International Journal of Production Research, 46(10), pp. 2707–2742. doi: 10.1080/00207540601064773.

Schaefer, S. M. and Alvesson, M. (2020) 'Epistemic Attitudes and Source Critique in Qualitative Research', Journal of Management Inquiry, 29(1), pp. 33–45. doi: 10.1177/1056492617739155.

Steffen, J. H. et al. (2019) 'Framework of Affordances for Virtual Reality and Augmented Reality', Journal of Management Information Systems, 36(3), pp. 683–729. doi: 10.1080/07421222.2019.1628877.

Uva, A., Gattullo, M., Manghisi, V., Spagnulo, D., Cascella, G. and Fiorentino, M. (2017). Evaluating the effectiveness of spatial augmented reality in smart manufacturing: a solution for manual working stations. The International Journal of Advanced Manufacturing Technology, 94(1-4), pp.509-521.

# Appendixes

In the creation of the guides and transcribing's, the work was split evenly between the two authors.

## Appendix 1 – Raw data, transcription of interviews

### Transcript of interview with Operator 1 , 2020-03-12

### Interview 1, related to observation 1 (Paper used)

Respondent (RE)
Ibrahim (IB)
William (WI)

IB: How satisfied are you with the current way of working?
RE: Yeah, yes it works well, taking the current conditions in to account, I think it is rolling on good. I haven't had so much to compare with either so, but yeah, that I think
IB: How confident are you in the current way of working?
RE: A lot!
WI: Why? or.. how?
RE: Yeah, I have been doing this for twelve years now, so so the… yeah I feel very safe in the old way, so it is... that's how it is.
IB: So its…? With the time then?
RE: Yeah yeah
IB: Yes… What is the pros and cons of the current way of working, do you think?
RE: Uhmm? Instruction wise, you mean, or?
IB: Yes!
RE: Yes…
IB: The way you receive instructions on.
RE: The con would be a lot of paperwork, it has to… it has to be printed, you're not allowed to, you're not to save old ones either… because it has to be fresh, incase …. if they change anything. It could, if you have an old one and it's changed and…. so that is a con if… yeah…
IB: Its because secrecy, do you mean? That you have to get rid of old…
RE: Yeah yeah that you must do… yeah if someone in the office…. someone changes the any measures or… then I won't be informed while I have my old ones.
IB: Right! So it has to be kept updated?
RE: yes yes yes!
IB: So you mean it is an extra thing you have to keep an eye on?
RE: yeah yeah you have to and it's… you also have to check if they have made any changes, then it's the same thing… then it takes even more time to *inaudible*
WI: It is your responsibility to check it?
RE: yeah yeah, it is.
IB: but…. something special that you think is good, a pro, a clear pro, is there any?
RE: Nah… not really, I don't think so. it's so habitual so its… yeah, it becomes natural
IB: uhm… yeah… What difficulties in today's way of working? In other words, a little more specific rather than just what the cons are.
RE: yeah….
IB: something extra?

RE: It is that running…. it is… not running, but you have to go to the computers that might be occupied or that they have run out of paper or what *swear* ever. There is… there can always be something, it would be that then… It becomes a lot of paper and thing like that and you have to toss and clean and stuff
IB: The accessibility then perhaps, you can say?
RE: Yeah, you can say that.
IB: yeah, and that you want to be as good as possible
RE: yeah yeah, that's correct, thats right
IB: What do you think would have been an improvement to your current way of working?
RE: yeah…. it is difficult but….
IB: if you personally would get to propose something
RE: it is difficult but uhh…. *laughing* i dont have alot to compare to, but what you have(AR) seems interesting, It could be a fun thing and and so , but yeah…. really difficult, but there is always potential to improve and if you get used to stuff like that it will be good….
IB: If a change had occurred in the way of working, what would your attitude towards the change look like?
RE: I think it would be pretty positive, that it would be, it would be fun to… yeah…. I think it would be for the better, if it would a disimprovement then i would have reported it. In this case I think it would be for the better.
IB: If we take an example about… if you get rid of paper, and get a smart tablet for example... if you just imagine a small little … yeah...change… how would you feel about it?
RE: Yeah, I think it would work like that, of course… but also… in an environment like this you have to be careful with these things, the possibility of them breaking is big. yeah… but that you could have tested. We haven't tested, but we could have maybe brought up the blueprints on that too
IB: yeah
RE: … you know that…. yeah… you could test that too
IB: would you have been worried if they implemented a little tech and yeah… digital tools and objects?
RE: no…
IB: because you know…. yeah
RE: No I wouldn’t, you don't… if you don't know that you … if you don't know what it takes you don't start …. then… if you don't have the things… if you don't get it forward then you start…then... no no *swear*... its only… i think it would be good.
IB: so… would a work place like this support digitization and implementing of….
RE: Yeah yeah… that i think…. that i think
IB: okay
RE: now you probably wouldn't be able to digitize everything, but most of it at least.
IB: yeah
RE: So it is a little about the feeling of it, its difficult to get it both on paper and computer, as to say. You have to keep it in the back of your head anyway, you have to learn, that's how it is..
IB: alright, then we say thank you!

# Appendix 2 – Raw data, transcription of interviews

## Transcript of interview with Operator 1 , 2020-03-12

## Interview 2, related to observation 2 (AR used)

Respondent (RE)
Ibrahim (IB)
William (WI)

IB: What are your past experiences regarding AR ?
RE: nothing maybe tv games but this is really new for me
WI: have you heard about it before
RE: no
IB: how is it when it comes VR have you heard about that?
RE: No nothing really
IB: what differences do you experience about using AR as an instruction form, unlike paper form?
RE: Yeah yeah i'm positive i must say. Avoid running around to print out papers and so. they must be thrown away and away and also in the right place. the information is easy to zoom into and i don't need any glasses because of that. No no im positive.
IB: So it minimizes a lot of manual work then ?
RE: yes and it is always the latest version of instructions that i receive
IB: How satisfied are you with this work method?
RE: yeah, now it was the first time, so it a little…., not difficult, but it was a little bit of a strange feeling. But in the end i think it flowed quite alright. If you spend more than 10 minutes or so then yes, i think it's a good device.
IB: how easy do you think you will get used to this or adjust to this later?
RE: after one day then think then you are good enough, i think so..
IB: we say one week then?
RE: Yeah yeah i think so
IB: After the amount of time you have used AR, as a guess how long do you think you need to get to grips with AR to be as good as working with paper ?
RE: one day, one day. so then you can go into to everything and you can peace and quiet sit down and look through everything and if you starting working with then you learn all the time. like for example short cuts and stuff. its like computers and everything. You must sit down in peace and quiet and give it time. that's how i am anyway .
IB: How confident were you in this way of working?
RE: Er just with the machine i feel confident, but i was so sure because i had never worked like this before. but you never do anything if are not sure anyway. but i confident anyway. if it is used more you will become more confident. Yes i think so.
IB: what are the benefits and disadvantages of using AR as an instruction method ?
RE :The advantages is what i said from the beginning. avoid running around and printing out papers and throwing them away and so.
WI: Do you mean updates and so on ?
RE: yes then because then you always have the latest changes in the device. You always the information with you. The possibility to zoom easily is a nice feature, it's nice to avoid using reading

glasses. the information is big and you can’t miss it. Also to avoid asking someone else to read for you. yeah so i think a good device.
IB: Any clear disadvantages?
RE: well it's hard for me to say but. I thought it was ok to wear them but if you were them a whole day. i only wore them for 15 minutes, i didn't feel anything but it might feel heavy after sometime… But it is anyway much light than a welding helmet. so with that said i don't see any clear disadvantages in that respect , not yet anyway.
IB: what about the performance?
RE: that's hard… Maybe if there was a possibility to get a brighter lens
IB: How is that important?
RE: that's in case i need to read time belts (tidband) and stuff like that. Otherwise it doesn't really matter. but the slighter darkness can be nice also. Maybee a function to adjust this could be good ?
But in the manufacturing task i saw everything, it was just something i reflected over.
IB: What difficulties did you experience with this approach?
RE: no not really when i got in the the swing of things
IB: What do you think would have been have been an improvement in working this way?
RE: i don't know really. I thought it was impressive.
IB: would of you have liked more access to other information apart from instructions?
RE: yes drawings, but that could have been given as part of the instructions. But maybe not for this manufacturing task but there other tasks were this would be useful. With this i mean where you need need to control the product with the drawing.
IB: How would you attitude have been if this way of working had been introduced?
RE: im positive towards this approach. this will be the future. is very workable. if you was to have all the work tasks introductions it would be very good
IB: If you was to think when comes to ergonomics for longer usage?
RE: well what was it 15 mins i used it. i didn't experience the device as heavy. but of course maybe after 8 hours it might feel heavy. but no i think it felt good
WI: did it feel uncomfortable in anyway?
RE: noo i don't think so. it had some good adjustment possibilities.
IB: du you have anything to add ?

# Appendix 3 – Raw data, transcription of interviews

## Transcript of interview with Operator 2 , 2020-03-31

## Interview 3, related to observation 3 (AR used)

Respondent (RE)
Ibrahim (IB)
William (WI)

IB: What are previous experiences with AR
RE: I've never tried i before, but i have tried VR but that's a little bite different
IB: What was it like to use VR?
RE: yes it was a good an interesting experience, you are really immersed in the game.
IB: So it was VR game you tested?
RE: yes
IB: what differences do you experience about using AR as an instruction form, unlike paper form?
RE: It was so easy to get hold of the information, i could work at same time and still have information available in front of me. it was simple and easy. Although it felt a little bit clumsy in the beginning when i tried it. But with that said it was the first time i tried working with AR and think you just need more practice.
IB: do you prefer instruction through AR or paper?
RE: Yes i would say that i prefer AR
RE: Very simple to use
IB: How satisfied are you with this work method?
RE: I think it's very workable because i have glasses on all the time and they are part of my safety gear. I also didn't have to run around to find and get hold of information.
IB: how comfortable was it to wear the AR headset in these 20 minutes or so?
RE: i didn't really think so much about. But i had adjust them slightly to see better.
RE: One think that i found that was missing is i couldn't angle the instruction back and forward. So i couldn't lay it down on the table like paper for example. But maybe that can be updated.
RE: One little negative aspect was that AR headset is sending out some frequency that disturbs my welding helmet.
RE: And i don't know if it is to do with the observation camera or the AR headset itself.
RE: We have had this problem with other equipment before
IB: How confident did you feel when you was working with the AR headset on?
RE: The more time i had it on the more confident i became.
IB: How self-confident would be if you if you had no help with knowing
RE: i think i could learn how to use AR quite fast to
IB: You understood the whole design, and how it worked
RE: Yeah exactly yeah… I think it worked good. It was a little sensitive sometimes when i had to mount certain things on the workbench and then…. i was twisting it to mount it and then it reacted by opening menus.
IB: So it started to think that…..
RE: yeah yeah exactly so it would be nice if it had locked modes sometimes.
IB: right, so you just lock it

WI: So the differences between your regular safety glasses and the AR headset, do experience any difference between them
IB: To look through them
WI: yeah too look through them
RE: Vision wise…. I didn't think so much about it because….
WI: did you see everything?
RE: Yeah you see pretty good…. ehhm…. it also prone to get scratched in this kind of environment… but you have to have feeling
IB: What are the pros and cons with AR as an instruction method? If you just present it very plain and straight.
RE: Positive parts is that i think it's very easy to get info you don't have to run around… ehhm, I don't know how deep you can go into this but all the info is there and it can also scan and i could sit next to my workbench the whole day and work with this
IB: so it will be more work and less running around
RE: And if I could communicate…. yeah I don't know how advanced it is
IB: there is probably a lot you can do
RE: negatives yeah…. it disturbed my welding helmet if it was that. It is a little sensitive with the mounts and it was also the fitment, i had to push it down and I also couldn't …. I don't know… adjust axis wise
IB: yeah you couldn't roll…
RE: yeahh
IB: the adjustment was limited
RE: yeah it was that…. but… I think yeah *laugh* it was very smooth
IB: This is also a little repetitive but… What difficulties did you experience with this work method? And we will do this… we angle it generally, it doesn't have to be only with the headset. General difficulties while wearing the headset while working. Any obvious difficulties?
RE: that would be if you maybe would lean over a detail and when you are twisting and stuff say if you are up and down and the weight itself makes it fall down
IB: right
RE: that is that then…Otherwise it isn't really
IB: no but it is a really good point. Did you feel like you had to think about it when you were working?
RE: No not right now, but I can imagine certain times we have here where you have to look over, but that is only temporary.
IB: Right! it is very good that you mention that…. yeah
WI: I was also thinking about the charging
IB: what did you say?
WI: the charging itself
IB: yeah
WI: *Inaudible*
IB: What do you think would have been an improvement to this work method? If you were allowed to pick yourself. It can be anything between how it looks and functions
RE: that would be if they became as smooth as glasses, as light as possible. And if you could integrate them with my welding helmet it would be even better
IB:Integrate?
RE: yeah

WI: can you use regular glasses while wearing welding helmet?
RE:It is very tight. but there is people here that have reduced sight ability that have glasses. So it's… no but if you could integrate it in the welding helmet it would be really good, then i have everything there. If they could read the blueprints meanwhile i am welding all from temp to measurements. yeah…. unevenness
IB: right, it takes these variables and gives you status
RE: yeah, right!
IB: really good
RE: that would remove a lot of work *laugh*
IB & WI: *laugh*
RE: it has to do with quality and everything… so if it could
IB: there is a lot of potential
RE: yeah there's a lot of potential
IB: So to round this here…. How would your mindset look like if this work method got implemented? As a final conclusion….
RE: Yeah I wouldn't have any problems with that
IB: you support that?
RE: yeah!

# Appendix 4 – Raw data, transcription of interviews

## Transcript of interview with Respondent 2 , 2020-03-31

## Interview 4, related to observation 4 (Paper used)

Respondent (RE)
Ibrahim (IB)
William (WI)

IB: How satisfied are you with the current method of instructions?
RE: Cumbersome, it takes up alot of workspace because i have to move all the papers around. They are also burnable, so i can't have them close to me while im welding for example. And handling all the papers is also cumbersome.
IB: So you are more dissatisfied than satisfied?
RE: yes i am
WI: When you are finished with the papers, will you use them again or do you have to throw them away?
RE: They have to be thrown away. Because it has do with ISO requirements, for example they could be updated tomorrow and they won't meet the new requirements.
IB: So are there many steps that you have to think about?
RE: yeah yeah, every time i have to print out a technical drawing, i have always check the edition. If it's not the correct one then i have to try and find the right people so i get the correct version.
IB How confident are you in the current form of working?
RE: Yes i feel very confident because i have been doing this for a long time. But there always some inconveniences with this way of working.
RE: Yes the papers take a lot of space and in the way a lot of the time And sometimes information is missing so i have to go back to the computer and print out even more paper.
IB: Do you notice any more specific disadvantages with this current way of working compared to AR ?
RE: Well i tested AR before this interview and i noticed i get the information right in front of me hear and now. And the possibility to place the instructions were i want to.
IB: have you always thought this way about paper instructions.
RE: yes i've always known about these issues and it takes up alot of time. Currently there is a lot of paper handling not just instructions, it can also be for example worklists and various other papers with important information. They have to put up on notice boards and so on, but if everyone had a AR headset the could have their "own room".
RE:: So this could minimize the risk of misunderstanding and that everyone gets right updated version of information. The right communication is always important.
IB: So if we was to be more clear what the pros and cons with working with paper instructions?
RE: All the paper handling i see as negative. Have to wait for an available computer so i can print out the papers. Sometimes i have login to my specific account and this takes more time. The positives well.. it's probably a cheap solution in the beginning but inte the long run it's probably not because of certain agreements with our the company of our printer and so on.
IB: If you think about using the paper instructions are there any difficulties there?

RE: Some things are hard to explain in text/litteratur. For example when im welding its very hard to understand how welding works and to explain this in text is very difficult. I could describe it as trying recreate picasso's paintings with to help of text. So it's not always so easy.

IB: So what you mean is that certain things you can't explain with text.

RE: You have to use your experience to explain these things.

IB: How important is it with the physical condition of the papers?

RE: I've never really thought about that. But when you mention it's very important to keep an eye on have much ink is left in the printers. Another thing if the you look at the drawing of the instructions you can see the they are black and white. sometimes it's hard to see what's happening in a black and white picture. We could probably solve this with color printers, but this would be more expensive.

IB: what do think could be better with this current way of working with paper instructions?

RE: It could be if everyone had there own laptop maybe.

IB: so you would rather get rid of the papers all together then ?

RE Yes i would rather get rid of all the papers and have access to a personal computer or something similar.

RE: of course computers take space as well but it would be better than paper instructions

WI: I was just wondering how close you can have the paper instructions when you are welding for example.

RE: Yes I have to move them far away from me.

WI: because of the potential fire hazard?

RE: We have certain rules of have faraway the papers have to be kept.

# Appendix 5 - Interview guide, Paper

**Interview guide**

**General Interview Questions**

- How satisfied are you with the current way of working?
- How confident are you in the current way of working?
- What are the pros and cons of the current working method?
- What difficulties do you experience in today's way of working?
- What do you think would have been an improvement to your current way of working?
- If a change had occurred in the way of working, what would your attitude towards the change look like?

# Appendix 6 - Interview guide, AR

**Interview guide**

**General Interview Questions**

- What are your past experiences regarding AR?
- What differences do you experience about the use of AR as an instructional form, unlike paper form?
- How satisfied are you with this type of work method?
- How confident were you in this way of working?
- What are the advantages and disadvantages of using AR as an instructional form?
- What difficulties do you experience with this approach?
- What do you think would have been an improvement to this way of working?
- How would your attitude have been if this way of working had been introduced?