CHALMERS
UNIVERSITY OF TECHNOLOGY

Evaluation of New Technologies within Manufacturing Engineering

Application of Virtual Reality in Automotive Industry's Manufacturing Engineering Processes: A Case Study at CEVT

Master's thesis in Production Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Cover: Man wearing Head Mounted Display (Jabil, 2019)

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Abstract

As the manufacturing industry is getting more competitive the need for new supporting technologies is increasing. Recently, the market for Virtual Reality (VR) has expanded significantly and become more accessible for consumers, with driving forces being the gaming industry and Industry 4.0. Therefore this technology will need to be researched and evaluated to further understand if and where it can be used and implemented. To do this, a method needed to be developed. The aim and purpose for this thesis was set accordingly, to find a method for evaluating new technologies and to see what the result from the implementation would be from a sustainability perspective. The thesis includes a case study at an automotive company where the method was developed and validated. The purpose and aim were fulfilled by creating a new and functioning method to evaluate new technologies within manufacturing engineering and identifying application opportunities. The method includes three major steps: a data collection, mapping of the findings and a verification of the result through a physical test.

By following the created method resulted in an identification of three improvement areas: analysis, communication and visualization. Within these three areas a set of 17 activities, at the case company, were found. The findings shows that an implementation of VR in these activities would result in improvements for the case company. Recommendations to the case company are to implement VR in the found activities, for example communication and ergonomics. Further research could include integration of VR peripherals, where haptic feedback should be prioritized, and to then study the effects on cost, quality, time and user experience.

Keywords: Virtual Reality, Manufacturing Engineering, Case Study, Evaluation method, Automotive industry, Industry 4.0, VR.

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Anton Johannesson and Julia Persson Giolitti, Gothenburg, May 2019

Acronyms

3D Three-dimensional. 6, 8, 11, 15, 39

AR Augmented Reality. XLIII, XLIV, 3, 6

BHI Bare Hand Interaction. 11
BIM Building Information Modeling. 16
BiW Body in White. 26, 27, 31

CAVE CollAborative Virtual Environment. 8, 9, 13
CEVT China Euro Vehicle Technology AB. XXXIX, 3, 26–28, 30, 32, 33, 40, 45
CPS Cyber-Physical System. 18

FOV Field Of View. 6–9, 11, 29, 44

HMD Head Mounted Display. XLIII, 3, 7, 9, 11, 12, 16–19, 29, 40, 44, 51

IMMA Intelligently Moving Manikin. 31
IoT Internet of Things. 17
IPS Industrial Path Solutions. XXXIX, XLII, 12, 30–32, 39

ME Manufacturing Engineering. XXXIX, XL, XLII–XLIV, 1–3, 21, 23, 24, 26, 28, 29, 32, 35, 40, 42, 43, 45, 49, 51–53, 55
MR Mixed Reality. 6

PLM Product Lifecycle Management. 39
PPI Pixels Per Inch. 9, 19

R&D Research & Development. 1, 41

T&CF Trim & Car Final. 26, 27, 31, 39, 40

VAC Vergence-Accommodation Conflict. 16, 19
VR Virtual Reality. XXXIX–XLIV, 2, 3, 5–18, 21–23, 26, 29–33, 35, 38, 40, 43–47, 50–53, 55

Contents

List of Figures

List of Tables

1
Introduction

This chapter presents the background for the thesis explaining the context of the subject and why it is relevant. Research questions, purpose, aim, scope and delimitation are also stated here describing the focus of the thesis.

1.1 Background

Manufacturing Engineering (ME) is described as the process of transforming materials into products (Davim, 2015). ME consists of the development of manufacturing systems and processes, which also includes machines, tools and other equipment needed to create a product. The planning of the manufacturing systems, processes and practices is also a part of ME. Davim (2015) states that joining methods, material properties, automation and lean manufacturing can be seen as fundamental subjects within ME.

The way manufacturing is performed today have been affected by globalization, competitiveness between companies have increased and Research & Development (R&D) have seen a large increase in time and money (Szabó, 2018). This has led to a rapid increase in the development of new products. The automotive industry is a prime example of this as the development time and the time to market of a new model have decreased significantly over the past few decades. The range of the products have also increased, and the product life cycles are becoming shorter (Szabó, 2018). This have increased the importance of production ramp-up processes. Part of companies' success are relying on an effective ramp-up process since a delay in the ramp-up can have great negative effect on the revenue (Szabó, 2018).

Simultaneously as the time to market needs to be shorter, the product design complexity has increased leading to more challenges for the manufacturers (Nieuwenhuis & Wells, 2015; Lawson, Salanitri, & Waterfield, 2016). The competitiveness between companies is increasing the demands on higher quality on the manufactured products (Lawson et al., 2016). Therefore, the quality of the manufacturing systems needs to be high since the process of recalling products is expensive (Szabó, 2018). According to Stoycheva et al. (2018) the demand for sustainability is also growing and sustainable manufacturing have gained attention. Sustainability can be divided into three different aspects: environmental, social and economic (Ayers, 2017). The manufacturing industry affects all three of the aspects. According to Statista (2019b) in 2014, 19.2% of the worldwide CO_2 emissions originated from manufacturing and construction. Stark, Seliger, and Bonvoisin (2017) state that the social aspects are affected by the working conditions for the operators at the manufacturing plants. Stark et al. (2017) further states that in 2016 manufacturing was responsible for 31% of the worldwide gross domestic product. Since manufacturing impacts all the three aspects it is important that it is driven forward by improved ME. Even though sustainable manufacturing is an attractive goal, it has faced many difficulties. In more competitive markets, such as the automotive market, the difficulties have been more significant (Stoycheva et al., 2018).

All the mentioned challenges above are something that needs to be addressed. For automotive companies it is essential to adopt new supporting technologies that can make it possible to overcome these challenges (Lawson et al., 2016). One of these technologies is said to be Virtual Reality (VR) (Lawson et al., 2016). VR is a technology that has been increasing in its worldwide market size the recent years (Statista, 2019a). It is also expected to expand in the coming years further increasing in worldwide market size (Statista, 2019a). Currently there are many advancements of VR with new innovative technology being brought to the market. Varjo and Pimax are examples of VR companies that are working with advancing VR technology (Varjo, 2019; Pimax, 2019). Both these companies have recently received investments for their development of VR technology (Varjo, 2018; Hayden, 2017). VR has made it into many different industries. Entertainment in the form of games is an industry where VR has become popular but there are many other industrial sectors as well. According to Statista (2019a) education, design and healthcare among others are sectors where VR has gained ground. ME is another sector where VR has been applied and shown to be beneficial (Berg & Vance, 2017; Lawson et al., 2016).

1.2 Research questions

Based on the background the thesis aims to answer the following research questions:

- How to evaluate the applicability of new technology in ME processes?
- What are the application opportunities between available VR technologies and ME processes?

1.3 Purpose

The purpose of this thesis is to create an evaluation method to find applications opportunities for VR technology within ME. This will support the advancements within ME to become more sustainable by studying the effects of the applications with respect to environmental, social and economic aspects.

1.4 Aim

Two aims are defined for the thesis. The first aim is to contribute to the research and development of the knowledge of how to evaluate if new technologies are applicable or not within certain ME processes. The second aim is to find areas where the use and applications of VR technology can be beneficial in terms of quality, time, cost and user experience within the ME processes. This will potentially lead to a more sustainable way of working with manufacturing changes. The project will generate the following:

- A method to follow when making the evaluation of new technologies.
- Areas of application for VR within ME processes.

1.5 Scope and delimitations

The project length is 20 weeks and started the 21st January 2019. The thesis will be created in collaboration with China Euro Vehicle Technology AB (CEVT) and Chalmers University of Technology. A case study at CEVT enables a practical example to support the thesis and the presented method for evaluation of new technologies. The following delimitations have been made to the project:

- The project will only study the ME processes at CEVT.
- The project will only focus on VR technology and not on Augmented Reality (AR) technology or other similar technologies.
- The physical testing will only be conducted on existing models and available VR technology at CEVT.
- The project will not include any development of VR technology.
- The thesis will have focus on the Head Mounted Display (HMD) technology because it is currently available for the ME department at CEVT. Other VR technologies will be presented in short but will not be evaluated or mapped.

2
Literature Study

The information found from the literature study is presented in this chapter. Firstly, to understand what VR is, general information about VR and different VR hardware and software technologies is described. After that, the found application areas of VR are presented showing where VR previously has been used. The VR user experience is then presented, describing factors that can impact the user experience. The driving forces for VR are then presented, explaining why VR technology is relevant and why there will be advancements within the area. Lastly, future advancements and trends within VR technologies is presented. An overview of the literature study chapter can be seen in Figure 2.1.

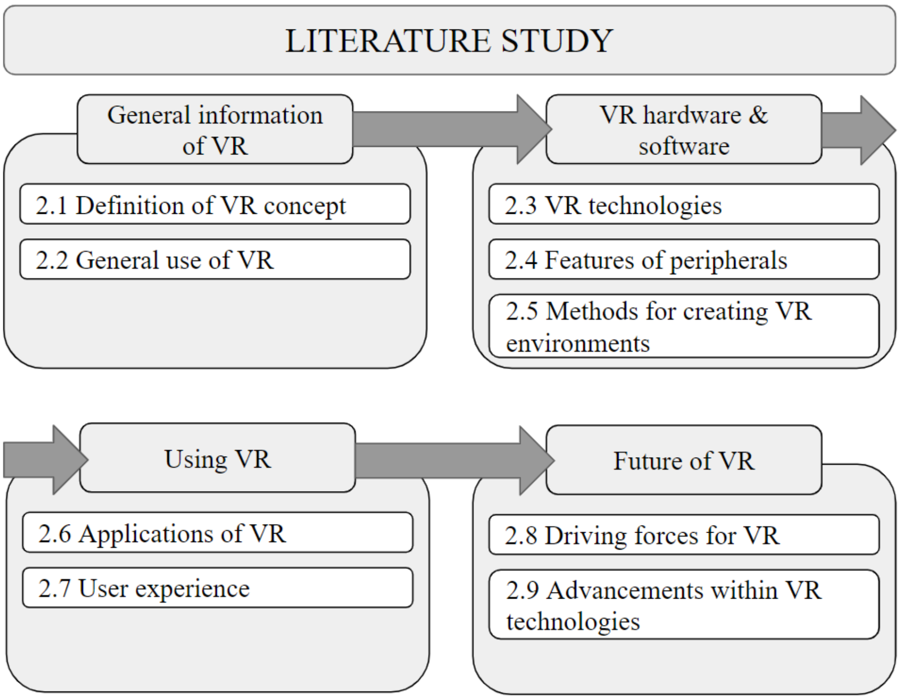

Figure 2.1: Overview of literature study chapter

2.1 Definition of Virtual Reality concept

There are many versions of the definition of VR. The definitions that can be found are often not identical but have many factors in common (Bryson, 2013; Reza & Eloi, 2018; Taupiac, Rodriguez, & Strauss, 2018). Jaron Lanier is the person who is said to have created the term "Virtual Reality" in 1980 (Peddie, 2013). Bryson (2013) made one definition, which states that VR can be defined as "... the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence" (p.4). This can be compared to the definition that Reza and Eloi (2018) give, which states that VR consists of three different properties that defines it. The first one being that the virtual environment is *interactive*. This means that it is possible for the user to interact with the virtual environment and change it. Secondly, the virtual environment is a *Three-dimensional (3D)* environment, which will provide the user with a perception of depth. This supports the feeling of immersion in the virtual environment. Lastly, the interaction the user has with the virtual environment happens in *real time* and gives direct feedback. Taupiac et al. (2018) also mention these three properties, *interaction*, *3D* and *real time*, as a part of the definition of VR. Many sources also mention that VR is trying to achieve a sense of immersion (Sherman & Craig, 2003; Reza & Eloi, 2018; Bryson, 2013; Peddie, 2013; Fast-Berglund, Gong, & Li, 2018).

VR is only one of many reality concepts on the spectrum from the fully real environment to the fully virtual environment (Eschen, Kötter, Rodeck, Harnisch, & Schüppstuhl, 2018). Kishino and Milgram (1994) call this spectrum for the *virtuality continuum*. Everything between the real environment and the virtual environment is what Kishino and Milgram (1994) and Fast-Berglund et al. (2018) call Mixed Reality (MR). VR is on the side towards fully virtual environment of the continuum (Eschen et al., 2018). Another reality concept is Augmented Reality (AR), which is also on the *virtuality continuum* but is closer to the real environment. AR combines the real environment with interactive augmented objects and aligns them with real objects (Fast-Berglund et al., 2018). VR is however the most developed technology according to Fast-Berglund et al. (2018) since it has been used and developed within the gaming industry for a long time.

2.2 General use of Virtual Reality

It is also important to know how the VR technology will be used and what it will be used for (Rückert, Wohlfromm, & Tracht, 2018; Fast-Berglund et al., 2018). Otherwise the wanted effect may not occur. Depending on what will be tested in the virtual environment different requirements will be put on the VR technology. There are many options for input and output devices that all have advantages and drawbacks. With a combination of different technologies and peripherals there will be different areas of use possible.

Rückert et al. (2018) propose five criteria that can be used to evaluate what VR technology to use:

- **Field Of View (FOV)**, which will increase the feeling of immersion.
- **Ease of maintenance**, will be affected by the complexity of the technology that is used. The more complex the technology is the more it will cost and be

difficult to set up, which may require help from external partners.
- **Mobility**, is important since the user may want to utilize the equipment on different locations.
- **Immersion grade**, will affect the result of the simulation. Immersion grade is highly dependent on FOV, the ability to interact with the virtual environment and how the real movements are transferred to the simulation.
- **Number of users**, is important to consider, as all technology may not function well with multiple users.

HMD performs well in all the categories except for number of users (Rückert et al., 2018).

There are three elements that are involved when using VR, according to Eschen et al. (2018). These three elements are object, model and human. The object is everything that exists in the real world except for the human, e.g. tools, floors and walls. The model is everything that is created virtually. The human is the person using the system and is interacting with the object and the model. Depending on the level of interaction, between the human and object or model, different reality concepts are to prefer. VR is suitable when the interaction between the human and model is high and the interaction between the human and the object is lower (Eschen et al., 2018).

2.3 Virtual Reality technologies

With regards to the sense of immersion there are different VR technologies that enable different levels of immersion. These can be divided into three different categories of immersion, presented in Figure 2.2.

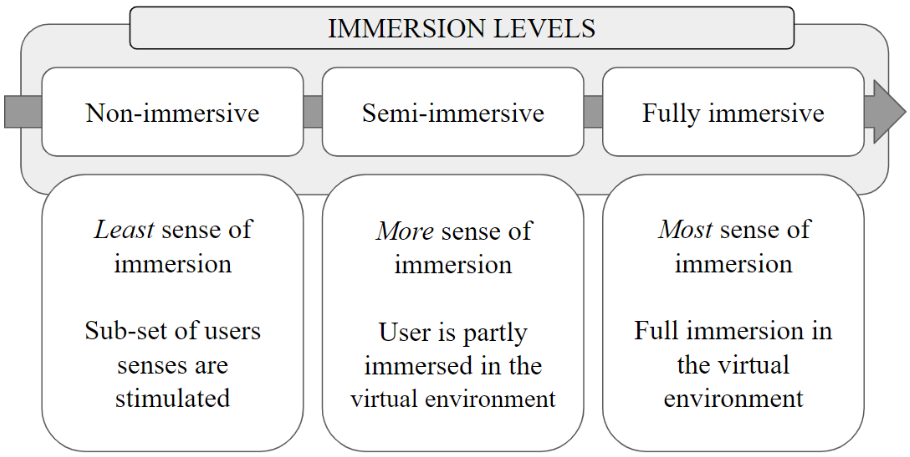

Figure 2.2: Categories of immersion

Rückert et al. (2018) explains that “The degree of immersion is depending on the field of view, the possibility of interaction, the transfer of movements from reality to VR and to which scope the real world is still perceptible.” (p.166). There are several different VR technologies available, an overview of some of the most common and well-known technologies is presented in Figure 2.3. with the level of immersion connected to the technologies.

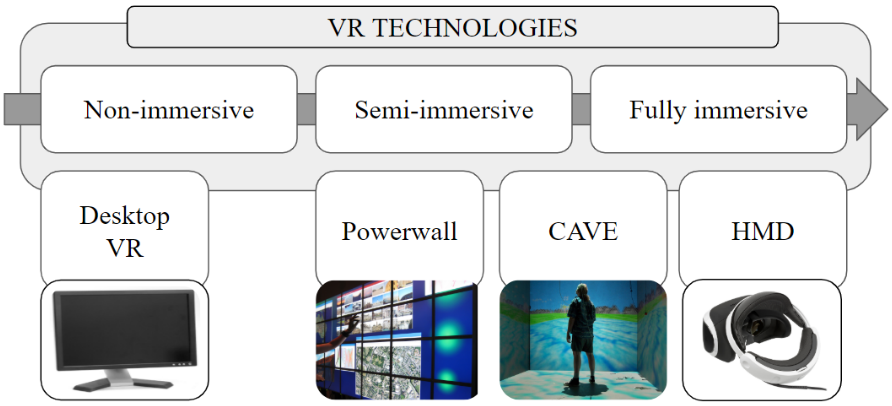

Figure 2.3: Categories of VR technologies

Source: (Amos, 2017b; Zzubnik, 2008; Rooch84, 2009; Pape, 2001)

2.3.1 Desktop Virtual Reality

Desktop VR is non-immersive and uses a desktop to interact with an environment (Lee & Wong, 2014). Göttig, Newton, and Kaufmann (2005) explains that it is a low-cost solution with a computer monitor rendering the 3D environment. Multiple different devices can be used to interact with the environment such as mouse and keyboard, joystick or gloves. According to Rückert et al. (2018) desktop VR performs poorly in FOV and number of users. The advantages of desktop VR are that it is that it requires low maintenance and that it is very mobile.

2.3.2 Powerwall

Powerwall is typically projection-based and Göttig et al. (2005) describes that the projection area creates a depth effect in the field of vision that generates a greater sense of immersion than desktop VR. An advantage of a Powerwall is that it is great for collaborations since multiple people can stand in front of the Powerwall at the same time. Disadvantages of the Powerwall is that it has low mobility and FOV (Rückert et al., 2018). The difference between CollAborative Virtual Environment (CAVE) and Powerwall is foremost the number of projection screens, which also is the reason CAVE is a more immersive technology (Göttig et al., 2005).

2.3.3 CollAborative Virtual Environment

Peddie (2013) describes CAVE as a room with three of its walls and the floor projecting images. These images are stereoscopic and with 3D glasses it creates stereo vision. The system is also able to track the location of the user to project the correct perspective to create immersion for the user. A drawback of CAVE is that it requires a larger investment and more resources to install. CAVE needs a special room built for it that can be complicated in an already established working area. Because of the complicated setup of a CAVE it also has low mobility (Rückert et al., 2018).

2.3.4 Head Mounted Display

HMDs produces stereo vision to create a sense of three dimensions and depth perception in the virtual environment (Reza & Eloi, 2018). This enhances the feeling of immersion, which is also greatly affected by the quality of the display. The HMD has built in accelerometers that makes it possible to track the movement of the user's head in all the six axes to calculate the position and FOV in the virtual environment (Peddie, 2013). Examples of HMDs are HTC Vive and Oculus Rift S (HTC, 2019b; Facebook technologies, 2019a).

There are multiple types of HMD with different characteristics that provide the user with various features that have advantages and drawbacks. The major features for HMD are high quality displays and FOV. There are HMDs that have displays with higher resolution and Pixels Per Inch (PPI). Higher resolution and higher PPI allows for more details to be seen in the virtual environment. The HMD could then be used for tasks that require the possibility to see finer detailing on the virtual objects. An HMD with a better display is also likely to be more immersive since it produces an image more similar to the reality (Cho, Kim, Jung, Shin, & Kim, 2017). A drawback with HMDs containing higher quality displays are that they require more computing power compared to the ones with lower resolution (HTC, 2019c, 2019d). Computer components that can handle the number of pixels and still produce enough frames per second without negatively affecting the user experience are an important factor. This will increase the cost for the VR setup since more powerful computer components are more expensive (Liagkou, Salmas, & Stylios, 2019). In those cases where the task does not require the possibility to see finer details of the virtual objects an HMD with lower resolution will be sufficient. A setup with this equipment will be cheaper since the needed computing power will be lower.

The FOV can also be different depending on which HMD is used. There are HMDs with larger FOV and those with smaller. The larger FOV creates a more realistic feeling and increases the immersion when being inside the virtual environment (Rückert et al., 2018). It also provides the possibility to see more of the environment at the same time. This can be useful when the task benefits from having a larger peripheral vision.

2.4 Features of peripherals

The VR technologies presented have different characteristics and areas of use dependent on which additional peripherals they are used in combination with. The peripherals are used to interact with the environment or enable deeper sense of immersion in the virtual world. Figure 2.4 shows an overview of current areas of peripherals circulating in the VR market and in Table 2.1 a summary of their features and functions can be seen.

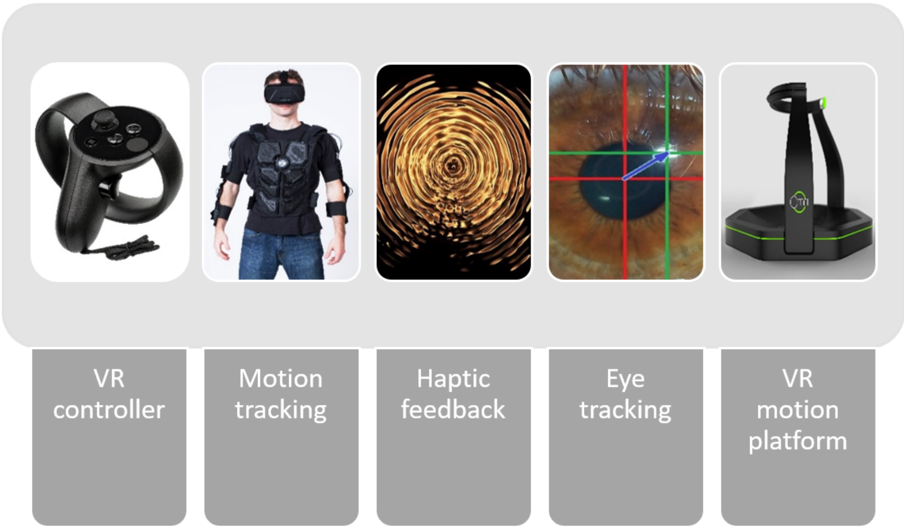

Figure 2.4: Current areas of peripherals circulating the VR market

Source: (Amos, 2017a; Minswho, 2015; Torrents, 2015; Markmann, 2015; Virtuix, 2013)

Table 2.1: Features and function of VR peripherals

Peripheral	Feature	Function
VR Controller	Virtual controller	Interaction by pressing buttons
Motion tracking	Tracking body	Corresponding body movements in virtual environment
Motion tracking	Tracking hand	Corresponding hand movements in virtual environment and interaction
Haptic Feedback	Apply motion to user	Generate the feeling of touch
Eye tracking	Data collection	Analysis of eye movements
Eye tracking	Gaze tracking	Interaction by gazing
VR motion platform	Walking in place	Unlimited walking in limited space

2.4.1 Virtual Reality controller

When using a VR controller, a virtual copy of the physical controller will appear in the virtual environment. This virtual controller will mimic the movements that the user makes with the physical controller. The controller can then be used to interact with the virtual environment. It is possible to use one controller for each hand. The buttons on the controller can be mapped to special functions, which provides the user with shortcuts to multiple interaction possibilities. VR controllers are relatively cheap compared to the total cost for a VR setup (HTC, 2019a).

2.4.2 Motion tracking

Motion tracking makes it possible to transfer the user's body movements and visualize it as a virtual avatar that copies the user's movement in the virtual environment (Fan, Murai, Miyata, Sugiura, & Tada, 2017). Fan et al. (2017) describe that motion tracking can be done by using optical markers attached to the body or other objects. These markers can be attached to a motion tracking suit that the user is wearing or directly on an object. Special motion capture cameras can then track the motions of the markers. A second way of performing motion tracking is by using an RGB-D camera, which can sense depth (Sra & Schmandt, 2015). This allows the motion capture to be done without the need for any markers. The Kinect is an example of a motion tracking system that uses an RGB-D camera (Sra & Schmandt, 2015).

There are many motion tracking devices that are made for only tracking the hands. Gloves with integrated motion tracking allow the hands to be tracked with precision and hand gestures can be programmed to represent different functions in the virtual environment. Another way to interact with a virtual environment is with Bare Hand Interaction (BHI). With this type of technology there is no need for any attachments to the user's hand for possible interaction with virtual objects (Vosinakis & Koutsabasis, 2018). Compared to using gloves with attached sensors BHI allows for free gestures with no constraints except being within the FOV of the sensors. The Leap Motion is for example a hardware that offers the use of BHI (Ultrahaptics Ltd, 2019).

2.4.3 Haptic feedback

Both motion capture suit and gloves can include systems for haptic feedback. Haptic technology is described by Sreelakshmi and Subash (2017) as a science of applying touch sensation and control to interact with computer generated environments. This means that when virtual objects are touched the haptic technology applies forces, uses vibrations or other type of motions to generate the feeling of touch for the user. These mechanical simulations create feedback for the user, which enhances the feeling of immersion in a virtual environment and can for example be used in controllers and gloves (Wu, Hsu, Lee, & Smith, 2017). An example, presented by Wu et al. (2017), is a 3D VR keyboard system. It combines haptic feedback in gloves with an HMD to simulate click feedback when using the keyboard in a virtual environment.

2.4.4 Eye tracking

Eye tracking is a technique of tracking or mimicking how the eye moves (Ungvarsky, 2017). The users eye movements are traced to where they are looking at any given time and in which sequence the user is changing location (Poole & Ball, 2006). The data collected from the eye tracking can then be analyzed and used in research (Blascheck et al., 2017). The possibility to know where the user is gazing can also be used to interact with the virtual environment. For example, buttons can be pressed by just looking at them.

2.4.5 Virtual Reality motion platform

A problem when walking around in a virtual environment using an HMD is that the user is restricted by the room where the VR setup is. By using a VR motion platform, the user will be able to walk in one place in any direction (Virtuix, 2019). This will remove the restraint given by the size of the room. The platform registers the movements, which are transferred to the virtual environment (Virtuix, 2019).

2.5 Methods for creating virtual environments

To be able to utilize the VR hardware technology it is needed to create a virtual environment that the user can work in. Two ways to create a virtual environment are through a simulation software or a game engine (Holubek, Delgado Sobrino Daynier, Košťál, Ružarovský, & Velíšek, 2017; Wang, Kim, Kobayashi, Wu, & Barth, 2018). Some simulation software have an integrated VR function that makes it possible to use the created simulation as a virtual environment for VR. Examples of simulation software with integrated VR tools are Process Simulate and Industrial Path Solutions (IPS) (Siemens, 2017; IPS AB, 2019). An advantage for this method is that the specialized functions for the simulation software are still accessible. A drawback is that the user is limited by the simulation software developer leading to that wanted changes may take long time to be released or never will be released. The ability to customize the software is also limited by the developer.

Game engines are usually used to develop games but can be used for other purposes as well (Wang et al., 2018). With the use of game engines a virtual environment can be created. Examples of game engines are Unreal Engine 4 and Unity (Epic Games, 2019; Unity Technologies, 2019). Game engines give flexibility in the creation of the virtual environment so that functions, menu layouts and options can be customized according to the demand of the user. The creation of the whole environment can be done by an in-house developer meaning that changes can be updated faster and easier.

2.6 Applications of Virtual Reality

In 1956 Morton Heilig, "considered by many as the "Father of Virtual Reality"" (p.412), presented Sensorama (Peddie, 2013). This was a visual experience display system with 4D effects where one person could experience sound, motion, scent and wind. Sherman and Craig (2003) present a timeline of VR technology history. It includes one of the first head-mounted displays (1968), the first public game with multiple players (1990) and the CAVE on display for the first time (1992). Technologies surrounding VR has been developed within several different industries for many different purposes. Some of the industries using or developing VR technologies are: gaming, education, healthcare, retail, engineering and manufacturing (Peddie, 2013; Bezegová, Ledgard, Molemaker, Oberč, & Vigkos, 2017).

When using VR tools for supporting simulation it is necessary to have a powerful computer with a graphics card sufficient enough for the task being performed (Holubek et al., 2017). This hardware is relatively expensive and have shown to be a restricting factor for implementing VR because of the high investment cost needed (Reza & Eloi, 2018; Berg & Vance, 2017).

Several areas are identified where VR is applicable and used. These areas are: communication, design, ergonomics, training, virtual assembly and visualization. Each sub-chapter explains the areas in more detail.

2.6.1 Communication

According to Berg and Vance (2017) it is important for everyone in a group to understand the problems at hand for a project to be successful. Reza and Eloi (2018) state that a common problem can be that everyone involved in a project is likely to not come from the same discipline. Each discipline also uses their own tools to communicate (Berg & Vance, 2017). Everyone may not be able to understand all the information in the usual form it is presented within a certain discipline (Reza & Eloi, 2018; Gong, Berglund, Saluäär, & Johansson, 2017). Communication is an area where where VR has shown to be very useful in (Reza & Eloi, 2018; Akpan & Shanker, 2017). By entering a virtual environment, the object in question can be seen from a common viewpoint and therefore it will be easier to discuss and understand. This will support the communication and decrease the effect of the gaps in knowledge about the subject. Cases have been identified where VR has been used to facilitate communication within collaborative design review and across discipline communication (Daily et al., 2000; Berg & Vance, 2017). Another area where VR has potential to be very useful in is communication from different physical locations by entering a virtual environment (Fast-Berglund et al., 2018; Lawson et al., 2016). This benefit with VR would entail both time and cost savings.

2.6.2 Design

According to Lawson et al. (2016) a design process is an iterative process that requires changes continuously and often the need to go back to older versions of the design. This will likely occur several times during a project and is a very time consuming and costly process. The decisions made early in the design phases can have a great effect on the total cost of the product. This is where VR has been shown to be beneficial, both saving time and money (Lawson et al., 2016). By using VR, virtual models can be created and reviewed to support the decision making and discover necessary modifications early. Since the quality of the rendering have improved so has the possibility to review the aesthetics of the product (Berg & Vance, 2017).

2.6.3 Ergonomics

Ergonomics is an area where VR has been found useful (Berg & Vance, 2017; Fan et al., 2017). VR is an effective tool for testing and analyzing in an immersive environment that is similar to the real world (Fan et al., 2017). According to Fan et al. (2017) the anthropometry of a person can have an impact on how a product is designed, and can make the design process difficult. It is also important to know how the design will affect people with different anthropometry. Fan et al. (2017) furthers explains that in the virtual environment the virtual body could be altered to represent another body with a different anthropometry. VR can therefore enhance the perception of affordance regarding the environment and objects around us. Berg and Vance (2017) says that there have been cases where operators have been brought in to the test facility to try out the virtual workstation. The operator can then give input on how well the workstation works. Ergonomists can also try out tasks in the virtual environment to estimate the forces needed to perform tasks in certain postures. This allows VR to be used as method to verify the ergonomic safety of assembly tasks (Berg & Vance, 2017). Lawson et al. (2016) discuss some areas that can be improved for the ergonomic evaluations. Haptic feedback of force and torque and the ability to track the body without using markers would make the evaluation more accurate and user friendly.

2.6.4 Training

VR has been shown to be an advantageous tool for work training (Harders, 2008). Firefighting, surgery, flight and manufacturing are examples of areas where VR has been utilized for training (Harders, 2008; Ho, Wong, Chua, & Chui, 2018; Liagkou et al., 2019). The advantage with VR is that it can create realistic simulations of the reality with a high level of immersion. This allows for engaging and interactive training from which the trainee can create personal experience. The use of a virtual environment also makes it possible to train in dangerous environments, which otherwise would not be possible because of the high risks it would involve. According to Ho et al. (2018) in complex assembly systems the level of training for new operators are essential to keep up the efficiency of the production. Ho et al. (2018) further mentions that VR training can save costs, reduce errors and improve quality compared to other training methods. The reduced errors will also save material and energy.

2.6.5 Virtual assembly

According to Winkes and Aurich (2015) errors in the assembly line is often first found when the new assembly is physically implemented. Changes at this point are very costly and therefore planning of the assembly is key for success. By using VR in the planning phase these errors can be found earlier in the project. Virtual assembly makes it possible to assemble and disassemble the product virtually and the necessary modifications can be made in the virtual environment (Lawson et al., 2016). This will save money compared to making the modifications on the physical assembly line (Winkes & Aurich, 2015). Virtual assembly have also shown to be advantageous in improving product quality (Lawson et al., 2016; Seth, Su, & Vance, 2008).

2.6.6 Visualization

VR enables the possibility to observe and interact with virtual objects and environments in 3D. VR also allows the virtual objects and environments to be seen in scale 1:1. These two capabilities makes VR a good tool for visualization. According to Akpan and Shanker (2017) visualization in realistic scale and 3D are advantageous for performing analyses. Akpan and Shanker (2017) further state that using VR as a tool for visualization during presentations is beneficial.

2.7 User experience of Virtual Reality

User experience is defined being a "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" (International Organization for Standardization, 2016). The relationship between VR and user experience have been discussed by several researchers (Reski & Alissandrakis, 2019; Reza & Eloi, 2018; Tcha-Tokey, Christmann, Loup-Escande, Loup, & Richir, 2018).

Bougaa, Bornhofen, Kadima, and Rivière (2015) present three categories that can be used for evaluating the quality of a VR user experience:

- **Immersion**: The feeling of being in a virtual environment.
- **Interaction**: A set of actions for the user to interact with the system and each other.
- **Autonomy**: The ability to adapt behavior to unknown changes in the environment.

A high feeling of immersion, interaction possibilities and autonomy increases the user experience, but it is also influenced by VR sickness.

VR sickness is stated by Kim, Lim, Lee, and Ro (2019) to consist of three different major symptoms:

- **Oculomotor symptoms**, which includes visual fatigue and having difficulties to focus.
- **Disorientation symptoms**, which might be dizziness and vertigo.
- **Nausea symptoms**.

These symptoms are mostly caused by the discrepancy between vestibular sensors and visual sensors, for example because you feel that you are not moving but you see that you are in motion.

Some suggestions for avoiding simulator sickness are to ensure the headset is properly adjusted, no unexpected movement, avoid acceleration and avoid fixed-view items. This is also connected to the processing power of the computer, both hardware and software influences the user experience (Fast-Berglund et al., 2018). If the VR setup cannot refresh the image fast enough undesired latency will be noticeable for the user (Regan & Pose, 1994). Cho et al. (2017) explain the screen door effect as what makes it possible to see the grid pattern between the pixels on the display. This effect directly affects our vision and lowers the feeling of immersion that may affect VR sickness.

According to Kramida (2016) Vergence-Accommodation Conflict (VAC) is a common problem for HMDs and can cause VR sickness. VAC is what occurs when the vergence distance and the accommodation distance for the eye does not match, see Figure 2.5. When wearing an HMD the vergence distance becomes the distance from the eyes to the focal point on the virtual object that the user is looking at. The accommodation distance is the distance from the eyes to the focal plane i.e. the display in the HMD. Kramida (2016) states that using an HMD can therefore cause visual fatigue. This fatigue is more noticeable during longer sessions.

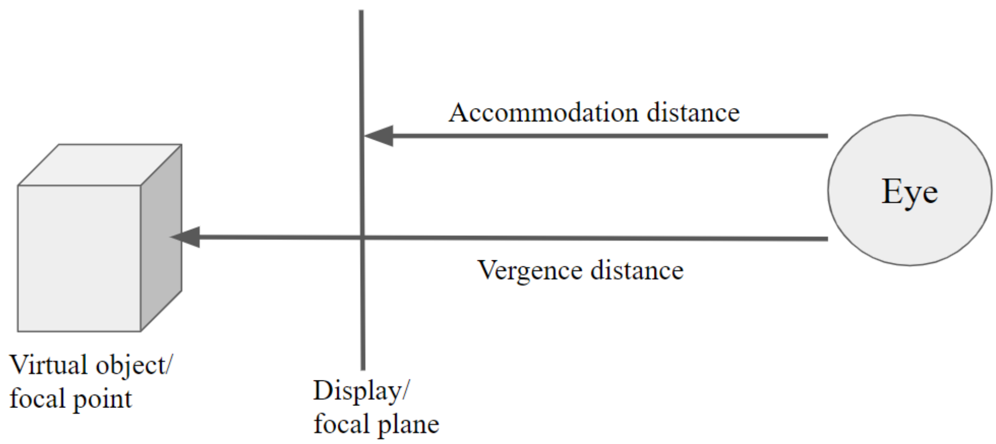

Figure 2.5: Illustration of Vergence-Accommodation Conflict

A study presented by Reza and Eloi (2018) where people participated to see how VR could be used in Building Information Modeling (BIM) processes showed that people quickly adapt to the VR environment. A large part of the participants found the HMD comfortable to wear during the whole sessions, but some participants expressed that they felt motion sickness and that over time it was tiring to wear the HMD. Another study also found that motion sickness is a drawback of the usage of VR (Gong et al., 2017). This study also showed that most of the test users found it easy to use the VR tool. According to Mealy (2018) there have been no thorough research surrounding the long-term health effects of using VR. This is something that needs to be evaluated depending on how long time the user is in the VR environment and how often the VR technology is going to be used.

2.8 Driving forces for Virtual Reality

(Statista, 2019a) state the market size for VR has expanded the recent years and is said to continue to expand. Two large drivers for the advancements of VR are Industry 4.0 and the gaming industry.

2.8.1 Industry 4.0

Manufacturers today act in an environment where they must be agile according to the changes that the customers are demanding (Fatorachian & Kazemi, 2018). Product quality, manufacturing costs and flexibility in production is forcing a change in the current production systems. Flexibility and connectivity are needed in the business processes to be able to satisfy customer demands in customization, quality and price. According to Fatorachian and Kazemi (2018) this is what Industry 4.0 is said to provide. It will be done by "...digitisation, automation and integration of production systems and through application of computer-aided programs and smart systems in manufacturing processes" (p. 637) (Fatorachian & Kazemi, 2018). Bougaa et al. (2015) discuss the use of VR in Factories of the Future, which is an equivalent of Industry 4.0. It is further argued that VR is necessary to implement in Factories of the Future because the systems in the future will have such a high complexity.

In Industry 4.0 all the physical processes will be monitored, and sensor data will be collected (Gilchrist, 2016). This will happen in real-time, which means that it will always be updated to the current state of the actual processes. This means that production processes can be improved by using the valuable data that is constantly given by feedback from the connected intelligent devices (Fatorachian & Kazemi, 2018). Gilchrist (2016) states that the data will then be linked to virtual models, which engineers can run simulations to modify and perform tests on. This will not affect the physical processes. All these virtual models can be referred to as the "digital twin". This digital twin will allow the engineers to improve the process and to reduce the lead times for implementations (Gilchrist, 2016). Internet of Things (IoT) is what will make the digital twin possible (Fatorachian & Kazemi, 2018). Fatorachian and Kazemi (2018) describes IoT as an environment where all the intelligent devices across the globe have the internet as center of connectivity. It is also stated that IoT provides "...greater insights and visibility and collaboration across the plant floor as well as greater real-time machine-to-machine connectivity" (p. 636). The virtual world and the physical world have been merging thanks to the interaction between embedded systems and their connection to the internet (Fatorachian & Kazemi, 2018). This merge is called Cyber-Physical System (CPS). Communication between humans, machines and products are possible because of the CPS. According to Ruppert, Jaskó, Holczinger, and Abonyi (2018) VR is an example of a CPS. Bougaa et al. (2015) have found VR as a technology that can be implemented in Factories of the Future and benefit multiple engineering processes.

2.8.2 Gaming industry

Gaming was, according to Mealy (2018), one of the first industries to embrace VR's potential and help push the VR industry forward. According to Parker (2017) the gaming industry is developing many games that are to be played in VR, which is showing that there is a large interest for the technology. The gaming industry is also investing a lot of money into VR for it to be adopted by more people, which keeps the development of the technology advancing. Parker (2017) states that the gaming industry is also said to lead other industries in evolving what VR can be capable of. Gaming consoles and mobile VR technology are said to be large contributors to the increase in revenue for the VR market.

2.9 Advancements within Virtual Reality technologies

The VR industry is constantly moving, and new technology and user applications are developed quickly. Statista (2019a) forecasts a continuous increase worldwide in the market size for consumer VR software and hardware. With the industry's continuous movement there are several potential advancements in the area of VR being developed. Based on the found examples presented in this section the VR industry is advancing to more realistic immersion and enhanced user experience. Found areas are standalone HMD, improved haptics, eye tracking and better displays, which are all under development.

HMDs that are standalone, i.e. that are not connected to any wires or computer, are gaining attention on the market. These HMDs are easy to set up and have high mobility since they do not require any additional equipment except for the HMD and possibly controllers. A drawback of the available standalone HMDs today is that some do not support tracking in all six degrees of freedom. Standalone HMDs are also not as powerful as an HMD connected to a computer. Though, over the recent years, more advanced standalone HMDs have been made e.g. the Oculus Quest (Facebook technologies, 2019b).

Both more realistic and precise feedback is wanted for haptics and forces when interacting with the virtual environment. There are suits being developed that will give more precise haptic feedback to the user's full body when being inside the virtual environment, for example the Teslasuit (Teslasuit, 2019). There are also companies, such as HaptX Inc. that are focusing on gloves that will give even more correct feedback, both haptic and force to the user's hands (HaptX Inc., 2019). Both stated examples are available for developers but not yet for the consumer market (Teslasuit, 2019; HaptX Inc., 2019).

As mentioned in Section 2.4, eye tracking can be integrated within HMDs giving it additional features. With eye tracking the user's focus can be traced to render that area in higher detail and decrease the quality of the peripheral vision to save computer processing power. According to Kramida (2016) varifocal displays that can alter the focal plane is one option to solve the problem regarding VAC. One way to achieve a varifocal display is to make the display alter the length between the eye and the display depending on where the user is looking, which eye tracking can do (Kramida, 2016). Oculus have made a prototype of an HMD that uses a varifocal display that moves (Lang, 2018b).

Development of displays with higher pixel density is also moving forward with many companies working to increase the PPI (Lang, 2018a). Higher pixel density displays will provide the HMD with better image quality giving a more realistic feeling, which also will allow details to be seen more clearly. According to Cho et al. (2017), the screen door effect of being able to see the grid of pixels will also be reduced. New displays that are being developed by Samsung and INT is said to have 1200 PPI respectively 2228 PPI (Lang, 2018a). This is a significant improvement compared to the 615 PPI, which is in the HTC Vive pro (HTC, 2019b).

3

Methodology

What type of research question is one of the most important conditions for choosing a research methodology according to Yin (2014). Since the research questions are divided in two areas, different methods are needed in support of the questions. The design of the overall methodology was therefore based on combining methods to be able to answer the research questions. To reach the aim of the project, the overall methodology was divided into three major parts: data collection, mapping and validation. Figure 3.1 shows an overview of the different stages in the project. Each sub-chapter contains more details of which methodology and methods were included in each stage.

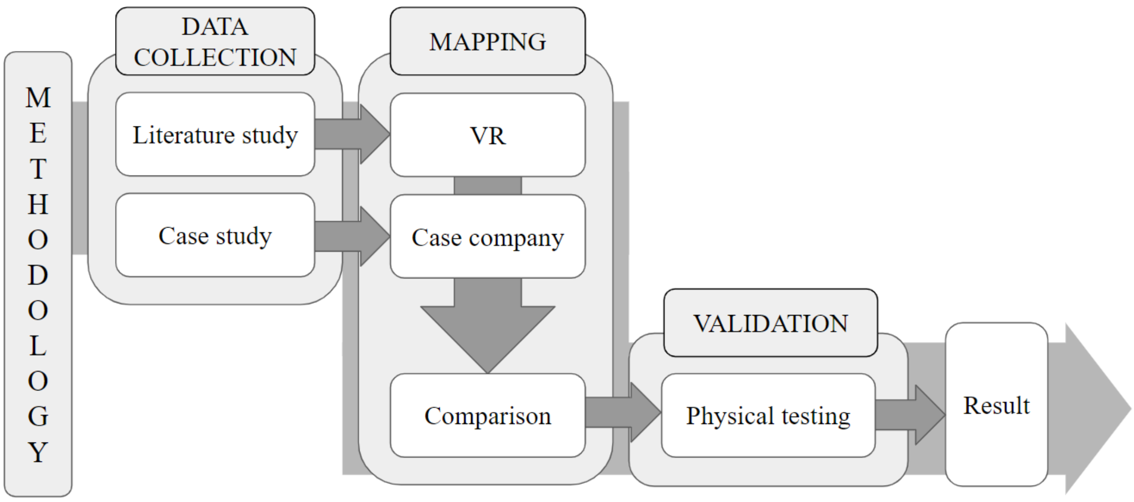

Figure 3.1: Overview of the project methodology

The data collection was performed to collect knowledge within the area of VR as well as ME processes. The two methods used were a literature study, which is presented in Section 3.1, and a case study, presented in Section 3.2. Both methods were performed in parallel. The two methods were used as a complement to each other to get a wider data collection, covering both the theoretical and more practical areas within VR and ME processes. The information from the data collection was used in the mapping phase, presented in Section 3.3. Both the available and application possibilities of VR and the case company's different actors and tasks relevant in the ME processes were mapped and compared. In the validation phase, presented in Section 3.4, the found application areas from the mapping were validated through physical testing where different hypotheses were explored.

3.1 Data collection: Literature study

The method for collecting the data for the literature study was a triangulation of three methods, presented in Figure 3.2. A triangulation is used for mixing multiple methods for increasing the support and outcome of the methods (Allen, 2017).

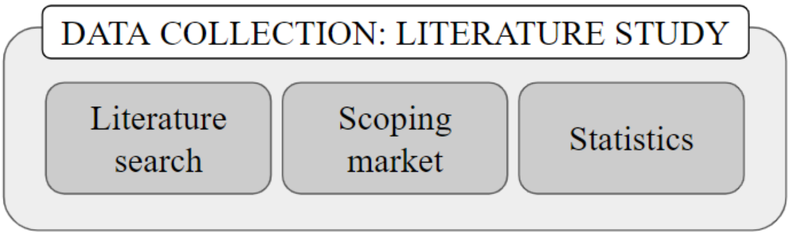

Figure 3.2: Literature study data collection methods

The literature search was performed to gain deeper knowledge within the areas of VR. The different areas that were researched were definitions of VR, history of VR, applications of VR within different industries and future technologies. The main approach was to search using search terms. According to Byrne (2017) there are two types of search terms, authors name or keywords and phrases connected to the topic. Some examples of the search terms used a are: "Virtual reality", "Virtual reality technology manufacturing engineering", "Automotive industry VR", "Virtual reality manufacturing processes", "Virtual reality application". The search was done through databases that are provided by Chalmers Library. Examples of databases that were used are: SpringerLink, ScienceDirect, IEEE, Google scholar and ProQuest. During the search the literature was structured according to possible area of use in an excel sheet for easier access and for creating a better overview of the researched areas. The sheet contained the following information about the literature: Title, Area of use, Database, Search word, Applied filter, No. hits, Date for search, Country, Year.

In addition of the literature search an analysis of the available technology on the market was made. This analysis was important to be able to answer questions regarding future technologies. The method was to scope the market and analyze the available technologies to be able to find information for the mapping phase. The scoping was done through an internet research of up-and-coming companies within the VR industry as well as scoping well established companies in the industry and their future products. This part of the research might differ in outcome depending on the researcher and case companies' interest and direction.

The data collection was also supported by a statistical analysis when this was applicable. The method for this research was to use the Statista database (*Statista*, 2007). This database is recommended by Chalmers Library since it contains statistics from market and opinion research institutions, as well as from business organizations and government institutions (*Chalmers Library Catalogue*, 2019). Keywords used for the research of statistics in the data base was: VR, virtual reality, virtual reality application, virtual reality market, virtual reality industries. The statistical data found was mostly connected to the status of the current VR market and the market in the future.

3.2 Data collection: Case study

A single-case study method was used as a part of the data collection with focus on the ME processes. A case study has a distinctive advantage according to Yin (2014) in situations when a contemporary set of events are researched, over which the researchers has little or no control. It is also considered a beneficial method when doing in-depth analyses of real-world cases. A case study includes a variety of data collection procedures, the use of multiple sources of evidence is considered a great strength of a case study data collection because any findings or conclusions is likely to be more accurate if they are based on several different sources of information. Yin (2014) also explains that not all sources are applicable for all case studies. Yin (2014) present six sources of evidence, two were not used for this case study. These sources were archival records and physical artifacts because these were not considered relevant in this type of case study. The remaining four sources were used through the case study to answer the research questions, presented in Figure 3.3.

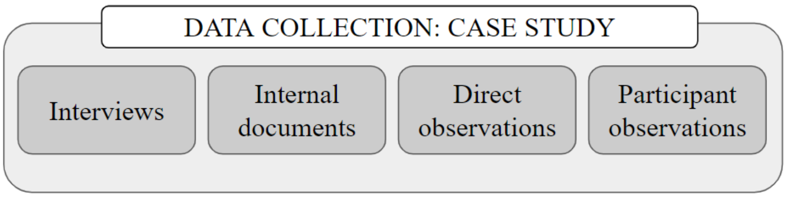

Figure 3.3: Case study data collection sources

These sources are explained more in detail in the Sections 3.2.1 - 3.2.4. In Section 3.2.5 the method of handling and compiling all data from these sources is presented. As a conclusion of the whole chapter, Section 3.2.6 presents the chosen company and its current advancements within VR.

3.2.1 Interviews

Interviews are considered one of the most important data sources for a case study (Yin, 2014). This method was chosen because it creates insight when studying human actions, which was necessary for mapping of ME processes at the case company. The interview study was used to identify application opportunities at the case company and identifying modes of interaction. The interviews were semi-structured, and the questions were predetermined and structured in different topics. This type of interview gives the researcher more control over the topics than during an unstructured interview but there is no fixed range of responses to each question like there is for a structured interview (Given, 2008). The topics were: department related questions, work tasks, IT tools, communication, challenges and VR. These topics were chosen for a way to structure the questions, which were developed in collaboration with both academic supervisors as well as a company supervisor. These topics were later used for structuring the summary of the whole case study data collection.

The selection of people to interview was made in collaboration with the department heads at the case company and the company supervisor. The suggested people were from different position within each department to generate a broad perspective and collect data from all work tasks within the departments. In total 15 interviews were conducted over a three week period. The interviewees were contacted by email and informed of the reason for the interview, that no preparation was necessary and that it would take approximately 1 hour. The location of the interviews was isolated rooms at the case company. The interviews were conducted by the two researchers where one was responsible of asking questions and the other were responsible for recording the responses by taking notes. The notes were summarized, and the key points noted directly after each interview. This division of work enabled the researchers to concentrate on their area of responsibility. After each interview the interviewee had the possibility of demonstrating their current projects or show some of their work tasks, this data collection method is presented in Section 3.2.3.

Comparing several extended texts can be problematic and confusing and a solution is to display qualitative data in matrices (Miles, Huberman, & Saldaña, 2014). This is explained as a good way to collect and organize data for easier viewing and preparing for cross-analysis with other information. Once all interviews were completed a summary of the collected data was created in matrices. When summarizing the interviews the same topics used to organize the interviews were used as matrix's areas. Categories were identified and were color-coded for easier overview of similarities and differences. These matrices were later used for analyzing the case study data collection and in the mapping phase.

3.2.2 Internal documentation

Yin (2014) states that documentation is most likely relevant in all case studies but that it is important to understand that the documentation was created for a specific purpose and objective and not created for the case study. The documentation studied in this case study was the company's internal documentation, which was made available by receiving access to the internal document storage space and the intranet. This documentation was studied in advance of the interviews to be able to understand the fundamental organization of the ME department at the case company. The documents were studied as a complement to the interviews and to strengthen the understanding of the organization of the departments. The documents also contained information about historical projects, which were studied from beginning to start to understand all phases of ME processes.

3.2.3 Direct observations

Direct observations are part of most case studies since they are normally performed in a real-world setting and provide additional information about the studied topic (Yin, 2014). The major observations during this case study were different types of demonstrations, which are summarized in Figure 3.4.

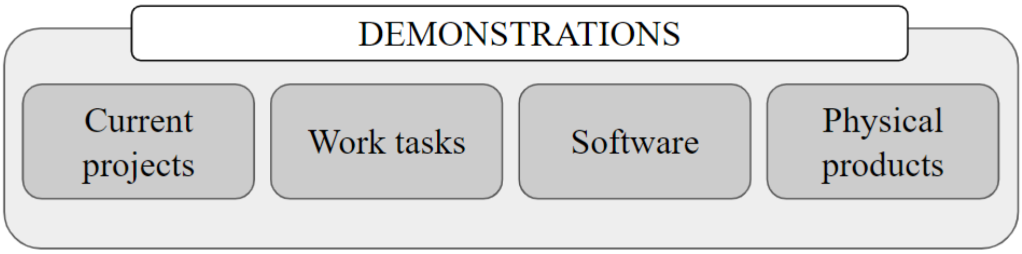

Figure 3.4: Demonstration areas

Some of the demonstrations were subsequent interviews when the interviewee had the possibility of demonstrating current projects, work tasks and the use of software. These demonstrations served as a complement to the interviews to gain a deeper understanding and a more in-depth analysis of the work processes. These demonstrations were not formally prepared or followed a structured method to be able to observe an as realistic as possible work process. Software were also demonstrated in more in-depth sessions where the demonstrator described and showed functions in the software. The use area within the company, the strengths and limits of the software were described. The final demonstration area was physical products, which were demonstrated by viewing virtual prototypes and physical test products.

Another source of direct observations was as a passive observer of different collaborative meetings. How meetings are conducted, which issues are discussed and the use of communication tools were observed. Reflections after these meetings were noted and later used in combination with all collected data for a better understanding.

3.2.4 Participant observations

Another form of observation was participant observation. This is a good compliment to direct observation, where the observer can participate in the actions being studied (Yin, 2014). Participant observations in this case study were testing of different technologies and software to gain real-life experience mostly within user experience. The testing included both unprepared and prepared sessions. The unprepared sessions were spontaneous and did not follow any structured method. The responsible person for the session invited to and held the demonstration where the researchers were able to participate and try functions of hardware or software. Notes and reflections were written after the session to capture the knowledge gained from the participation. The prepared sessions were planned in advance, with a purpose and desired result stated. After the session reflections were noted and the purpose and desired result were compared to the outcome and result from the session.

3.2.5 Analytic strategy of case study data collection

The first step in analyzing the data collected during the case study was creating matrices summarizing the interviews. These matrices were used as a base in a bottom-up approach of analyzing and summarizing the different types of data. The input from the rest of the data was used as additional or supportive information to the interviews. The summary was based on how the information could be relevant for answering the research questions and to prepare the information for the mapping and comparison phase.

3.2.6 Chosen case company

The case study was performed at China Euro Vehicle Technology AB, which is abbreviated CEVT. It is a development center covering all aspects of passenger car development and is a part of Zhejiang Geely Holding Group (Geely Auto, 2019). CEVT is an innovation center focused on finding smarter ways to build cars – through modular development, virtual engineering, and continuous innovation (China Euro Vehicle Technology AB, 2019). The vision of CEVT is "To be a world leading innovation center, creating mobility solutions for a different tomorrow.". To achieve this, it is of essence for the company to be at the forefront of innovation and technology, which means that VR is an important tool to evaluate to decide how much added value it might have to possibly succeed with the company's vision.

The study took place at the ME department at CEVT. The department works to ensure that the developed cars are possible to manufacture. ME is involved in the whole vehicle development project from start to finish, which consists of multiple milestones and parallel work processes. The ME department at CEVT consists of five major departments, Body in White (BiW), Geometry (GEO), Painting, Stamping and Trim & Car Final (T&CF). The departments focus on different areas in the vehicle factory. When manufacturing a car there are several ways of executing the processes and in which order they should be performed depending on which company or production facilities is studied. However, there are some general steps and organization which most automotive production facilities follows.

1. **Stamping**: The first step when manufacturing a car is stamping and forming of sheet metal. This process produces all metal parts of the car, which can be done both in-house and by external suppliers most common is to have a combination of both.

   The Stamping department at CEVT works to ensure that all metal parts of the vehicle are possible to manufacture.

2. **BiW**: The following step is to join all formed parts into a car body structure, the metal body of the car is assembled. Robot or manual welding are the most common processes. The car in this part of the factory is called a "Body in White", which is when sheet metal parts form the skeleton of the car, untreated and unpainted.

   The BiW department at CEVT works to make sure that the car is feasible to assemble from the manufacturing point of view.

3. **Painting**: The third step is the painting processes when the "Body in White" goes through material treatment processes and several different painting processes. These processes ensure the material is protected against for example corrosion and chipping as well as the car getting the correct color.

   The Painting department at CEVT works both as construction department (for example constructing the color and deciding where paint and sealing needs to be placed) and makes sure the processes are possible to execute to get the wanted surface.

4. **T&CF**: The final stage of the production line is when the rest of the car is assembled, the engine and all trim. Trim is all additional parts of the car, such as glass, handles, seats and electronics etc. Once all parts are assembled the car goes through multiple testing phases before it gets shipped to the customer.

   The T&CF department at CEVT ensures that the car is possible to assemble and makes it easy for the operators to do the right thing every time.

5. The **Geometry (GEO)** department at CEVT works to ensure that the car is manufacturable within the correct tolerances to assure the right quality

All ME departments at CEVT are organized in a similar way with some modifications. These modifications are dependent on mainly two differences. The first difference is in work tasks where some departments have additional work tasks needing special competence or work processes to perform that task. The other difference influencing the organization is the size of the departments. Some of the smaller departments have people covering several different positions and functions at the same time but in general there are some positions reoccurring at all departments. They are director, system manager, system project leader, manufacturing engineer and simulation engineer. In Table 3.1 the different purpose and work tasks are presented of each function.

Table 3.1: General functions and simplified description

Function	Description
Director	Head of the department
System Manager	Works to create an efficient way of working for the team and works with tasks that require core competences
System Project Leader	Leading projects and coordinating cross functional teams
Manufacturing Engineer	Plan the production process of a product in the most efficient, effective and economic way
Simulation Engineer	Creates virtual models to use for virtual testing of processes

3.3 Mapping

The mapping was made in three phases and different mapping techniques were used for different purposes, which is presented in Figure 3.5.

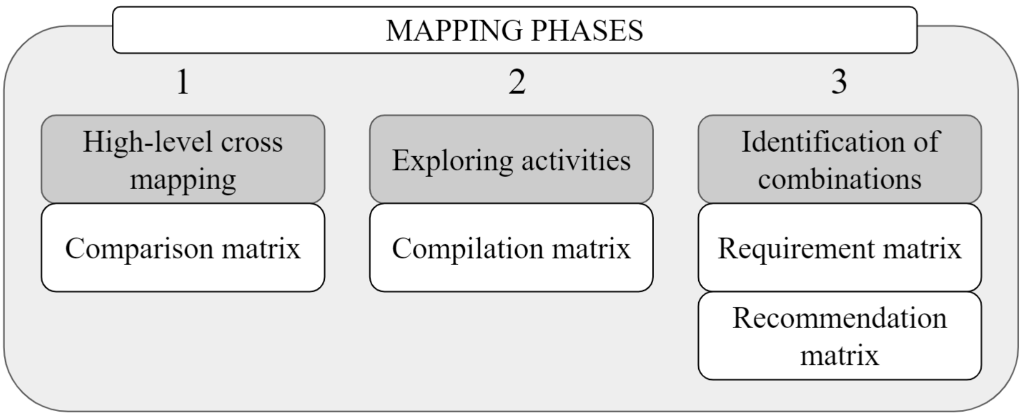

Figure 3.5: The three mapping phases

In the first mapping phase a comparison matrix was created to compare different application areas on a high level. Identified areas of application for VR were cross compared with areas of application at the case company. Identified areas of application for VR were found in the literature study. From the interview summary categories were identified and used as areas of application within the case company. When doing the high-level cross mapping weight was put on combinations where VR would be more beneficial for the category of application area at the case company. This map showed where VR was most suitable but also in which areas it should not be implemented in. Once this map was finalized the most similar areas were joined together for easier mapping in the second phase.

In the second phase a compilation matrix was created where each activity was explored and deeper described: how it is performed, with which tools, the purpose of the activity and what demands are connected to the activity. This was based on information from the case study data collection. The activities described were connected to the areas identified in the previous phase. This map was made in preparation for cross mapping the activities with VR in the final mapping phase. The demands on the activities were used as a basis for the requirement specification on VR.

In the final mapping phase VR applications were identified for each ME activity. The map was built in two steps. The first step identified which requirements different activities had on the VR application based on the demands on the activities from the previous phase. For each activity the demand on FOV and resolution of the HMD were defined as well as if haptics, motion tracking and controllers were needed for the activity. These requirements areas were based on the literature study data collection. In the second step recommendations of the suitable VR technology and peripherals were made based on what requirements each activity had and an approximate time span was stated based on which technology was needed.

3.4 Validation: Physical testing

A validation was necessary to perform to confirm and strengthen the results from the mapping. The method chosen was to perform a physical test at the case company with an evaluation survey connected to the test. The survey was used to gather data of people's opinion and behavior. The main purpose was to evaluate the potential benefits from using VR compared to regular desktop setup when performing different tasks since most of the identified activities at the case company are performed with a computer today. Two additional purposes were to make employees at ME aware of the VR initiative and to test different hypotheses to strengthen the mapping result. When developing the test four steps were followed, the overview of the process is presented in Figure 3.6. The sub-steps within preparation and design can be done in any order or parallel. The sub-steps within building and performing needs to be done in order.

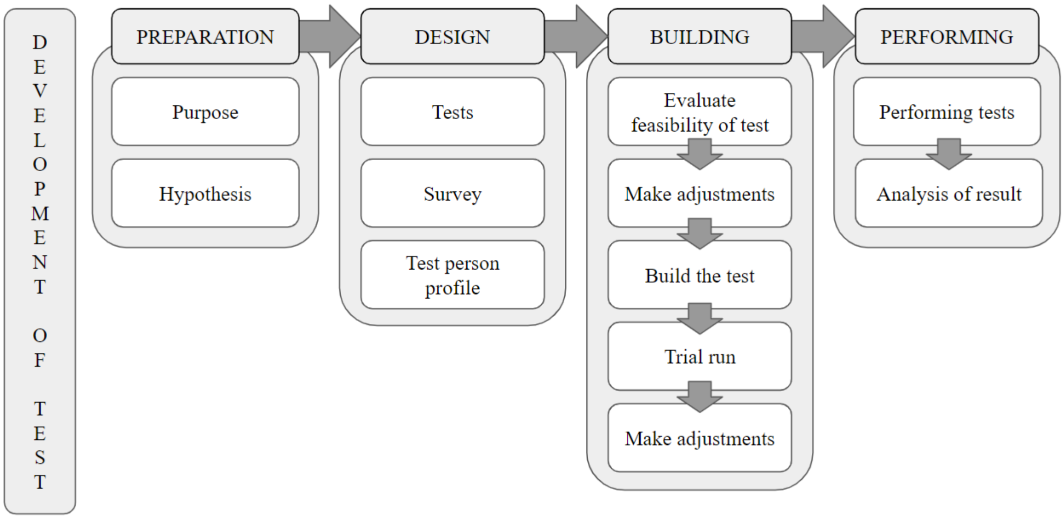

Figure 3.6: The four development phases

3.4.1 Preparations of the test development

When developing the test, the first step was to do the preparations. The preparations consisted of defining the purpose of the test and to state hypotheses that were going to be evaluated in the test. The four hypotheses were the following:

- **H1**: VR is preferred compared to a regular desktop
- **H2**: Estimations of changes when implementing VR in different activities will result in:
  - The quality factor will be evaluated to "Great improvements"
  - The time/cost factor will be evaluated to "Improved"
  - The user experience factor will be evaluated to "Improved"
- **H3**: When evaluating factors time is considered the most important, and communication is the area which is believed to be the most beneficial activity to implement VR in.
- **H4**: VR is believed to be a tool to utilize.

3.4.2 Designing the test

The next step was designing the test, survey and what profile the test person should have. The design of the test was made in collaboration with the supervisor at CEVT and an expert in the software IPS. IPS was the chosen software for building the VR environment in because this software had the best VR support at CEVT at the time of the development of the test.

The general idea was to have the test person first perform a task on a desktop setup and then do the same task in VR. However, the different departments at CEVT do not use the same software and have limited knowledge within IPS. To level out the differences in software knowledge it was decided to pre-record the task performed on the desktop. The pre-recording was done by screen recording the task being performed. The videos created were to demonstrate how the tasks were performed today. The videos were edited, and descriptive text was added to explain how the task was performed.

The test consisted of three different tasks, each task from different parts of the factory with activities identified in the second mapping phase. The first task was equipment verification, which is a part of the BiW area. The task was to identify which weld gun would be suitable for the welding station. Today this is performed with simulation in Process Simulate, which was the program used for recording the video. Two of the guns were approved in the simulation and in the VR environment the test person was to decide which of the two guns were best suited for the station.

The second task was an ergonomic evaluation of a sealing process in the painting area of the production. In the paint station there were two car bodies in different line heights with green markings in the front wheelhouse representing where the sealing was going to be placed. In the video the built-in tool Intelligently Moving Manikin (IMMA) in IPS was used for simulating the movement of several manikins and produce an ergonomic evaluation chart. In the VR environment the test persons were to experience the operators work position when placing the sealing with the paint gun on the two cars.

The third and final task was an assembly geometry assurance, which is a part of the T&CF area of the production. The video demonstrated the use of IPS' path planning function where two engine pads were evaluated if they were possible to assemble and with how much clearance there was to the surrounding components. In the VR environment the test persons were to assemble one engine pad in the car body.

After a test person had performed all tasks, both by watching the video and completing the tasks in the VR environment, a questionnaire was filled in. The questionnaire consisted of 5 bigger areas, where no. 2-5 is connected to each hypothesis (H1-H4):

1. Background of the test person.
2. Questions about desktop vs. VR.
3. Estimation of benefits within quality, time, cost.
4. Evaluating importance of different factors.
5. Use of VR in work processes.

When designing the survey Google forms were used for creating the questionnaire. The questions were closed-ended where the test person was provided with predetermined options to choose a response from. Some questions had multiple choice options when this was necessary. The survey was evaluated and adjusted together with supervisors and after feedback from trail runs.

When designing the test one critical part was to determine the test subjects. Both demands, and preferences of the person's profile were defined. The demand was set to that the person should have no or limited knowledge of using VR at the case company. This was because the pioneers within VR at the case company were not that many and their knowledge in comparison with someone with limited knowledge of VR would have had an impact on the result of the test. By leveling the knowledge of VR, the comparison between VR and desktop would be more valid. One purpose of the testing was also to make people aware of the existence of VR. The preferences of the test persons were decided to be simulation engineers or manufacturing engineers since they are of majority at the ME department but also whom most likely work with similar tasks and in the future also VR. The test persons were chosen through the directors of each ME department. They made their recommendations based on whom they felt suited the profile of the demand and preferences best. Three people from each department were requested. A generic number of people from each department were considered representative, even though the percentage of the participating people from each department would differ because of the differences in number of people at each department.

3.4.3 Building the test

Once the tasks were decided the feasibility of the test was discussed with supervisor at CEVT. Adjustments were made to the test to be better suited for the time frame, the competence of the researchers and test persons. Examples of adjustments were to reduce the number of weld spots and remove one engine pad. The actual building of the VR environment was in assistance with an expert in the software IPS where previous geometry and CAD files were used to build the three different tasks. Once the environment was built, trial runs were made, and the environment was adjusted according to the found complications such as clash detection, positioning of tools and parts as well as dealing with restrictions that the used computer set.

During the trial runs it was also decided on what information should be presented to the test person before, during and after the test. This was done to prevent influencing the experience and impressions of the different test persons, while the test was being performed. Points that were presented were the following:

- Presentation of the purpose of the test
- Presentation of how the test was going to be performed
- Emphasizing that the focus was not the software or the specific tasks, but the comparison between VR and desktop that was important.
- Short guide of how to navigate in the VR environment
- Explanation of what to investigate in the VR environment

3.4.4 Performing the test

When performing all the tests each test person was booked for one hour during which the different tasks and survey were completed. The test location was in the current VR room at CEVT with HTC vive setup. After a short introduction the first video was viewed and the same task was then performed in VR, then the second video was shown and so on. This order was decided since it provided the test person with easier understanding of which task was supposed to be performed in the VR environment. When the questionnaire was filled in it was possible for the test person to ask questions if there were any uncertainties.

4
Results

In this chapter the result is presented and consists of four parts, an overview of the structure of the chapter is presented in Figure 4.1. In Section 4.1, the methodology for the study is compiled so it can be used by others for evaluating how new technologies can be implemented. In Section 4.2, the collected case study data is presented with the most relevant areas deeper explained. In Section 4.3, the result from the three mapping phases are presented. The result from the physical testing is presented in the final section, Section 4.4.

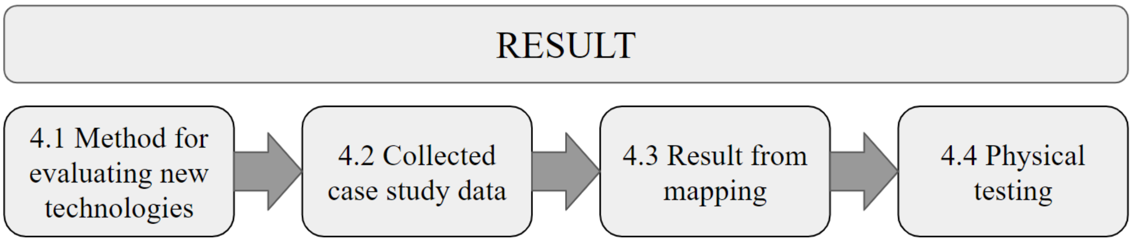

Figure 4.1: Overview of the result chapter

4.1 Method for evaluating new technologies

In this section the first research question is answered, how to evaluate applicability of new technology in ME processes. The methodology followed in this thesis is summarized and presented in this section as a method for evaluating new technologies. The evaluation method is based on previous developed method and tools, presented in Chapter 3. Through the case study this method was used to find application opportunities for VR at the case company. The overall steps for the evaluation method are presented in Figure 4.2.

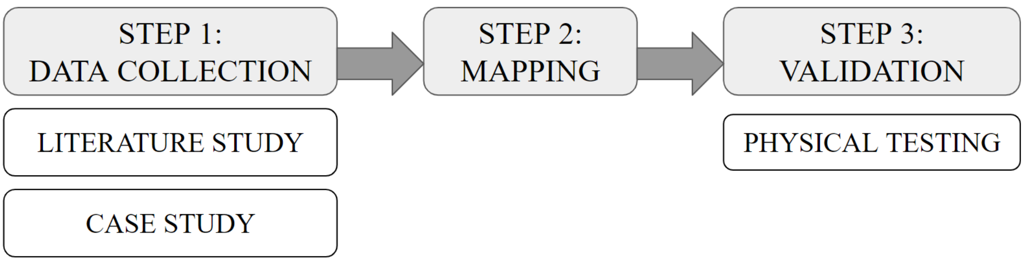

Figure 4.2: Method for evaluating new technologies

4.1.1 Step 1: Data collection

The first step is to gather the data needed. The literature and case study data are both equally important because they are the base for the rest of the evaluation process. The literature study is performed to research the technology. Points of research are:

- Definition and general use of the technology.
- The different type of hardware and software connected to the technology.
- Current application areas.
- Advancements of the hardware and software development.

The steps to follow when performing the literature study are:

1. **Search terms**: Set up terms to search for what type of information needs to be acquired, which should be connected to the above points of research.
2. **Databases**: Use the search terms in available databases. Suggestions of databases are: SpringerLink, ScienceDirect, IEEE, Google scholar and ProQuest.
3. **Structure**: During the literature study make sure to structure the information about the literature in for example an excel sheet for easier access to it later during the evaluation process.
4. **Scope market**: In addition to the literature study make a scope of the current technology market to generate additional information about the advancements of the technology.

The case study data collection is performed to investigate the potential application areas. When performing the case study, it is important to research the following areas:

- Organization of the department or company
- Type of work tasks performed
- Type of IT tools used
- How the communication is executed
- Challenges that are faced at the case company
- The current state of the researched technology

Tools for gathering this data are:

- Performing interviews
- Studying internal documents
- Making direct and passive observations

The steps to follow when performing the interviews are:

1. **Type**: Decide on the type of interview, unstructured, semi-structured or structured. This depend on what type of questions you decide to have.
2. **Questions**: Write the questions and do a trial run to understand how they can be interpreted.
3. **Topics**: Structure the questions in relevant topics to facilitate for the interviewee.

4. **Plan**: Plan the interviews. For example, what type of people is needed, how long time is required and what kind of information needs to be conveyed before the interview. The number of people to interview will differ between companies and departments depending on the size.
5. **Choosing people**: When choosing people to interview it is important to cover all type of work positions at the company or department that is researched. This is to gather sufficient data about all different work tasks performed. Involve upper management in the selection for choosing interviewees since they have best knowledge about the people's capabilities.
6. **Conduct interviews**: Conduct the interviews. Make sure to take notes or record the interview. Make sure to respect the ethics of the individual and that they feel comfortable during the interview.
7. **Summarize data**: Once all data is gathered, it should be compiled into a summary for easier overview of the collected data to identify the possible areas of application.

The steps to follow when studying the internal documents are:

1. **Plan**: Plan what you are looking for in the documents. It is easy to get lost in the company's documentation.
2. **Search**: Search yourself or get help from the people working at the company to make the search easier.
3. **Document**: Document the findings and connect it to the interview data.

The steps to follow when making direct and passive observations are:

1. **Plan**: Plan what the purpose is and what type of questions should be answered during the observations
2. **During observations**: During the observation make sure to ask questions to gain a deeper knowledge of the demonstrated task.
3. **Reflect and note**: Make reflections about the leanings from the observations. Document the findings and connect it to the interview data.

4.1.2 Step 2: Mapping

The second step of the evaluation process is mapping the findings from the data collection by following these phases of mapping:

1. **Compare**: Compare application areas of the technology and company to identify which areas are compatible.
2. **Explore**: Further explore the identified areas of application to understand how activities are performed today.
3. **Identify**: Identify combinations of the technologies for each activity with requirements and recommendations based on the literature study.

4.1.3 Step 3: Validation

The final step is to validate the result from the mapping through a physical test. By doing this it is possible to test if the found application areas of the technology at the company are correct and to gather more information about the attitude of the employees towards the technology.

1. **Prepare**: Define the purpose of the test and set up hypotheses that will be tested.
2. **Design**: Design the test, the survey and what test profile is wanted.
3. **Build**: When building the actual test, evaluate the feasibility of the test, what adjustments are needed for it to be better suited for the time frame and the knowledge of the test person. Make adjustments accordingly and then build the test. Make sure to do a trial run since most errors will then be found and adjust these so they will not occur again.
4. **Perform**: When performing the test make sure to stick to the time limit and that the same information is conveyed to each test person so that the risk of bias is reduced.
5. **Analyze**: Analyze the result from the test and compare it to the result from step 2 in the evaluation method. Identify the differences and evaluate the hypothesis.

4.2 Collected case study data

In this section the result from the case study data collection is presented. When analysis of the collected data was made matrices were created to summarize the different types of data. In this section the most relevant information from the case study will be highlighted and the full matrices can be seen in Appendix A. The highlighted areas are: IT tools, current VR status, communication and challenges.

4.2.1 IT tools

Common IT tools that all departments use are summarized and these are presented in Table 4.1.

Table 4.1: The common IT tools used at all ME departments at CEVT

Tool	Description
Sharepoint	Is a web-based collaborative platform that integrates with Microsoft Office and is used for document management.
Skype	Used as a tool for communication, also possible to share screens for easier distance collaboration.
Outlook	An email program for communication purposes and is also used for scheduling.
Office package	Tool used for documentation and presentation.
Teamcenter	Product Lifecycle Management (PLM) software from Siemens used for storing and sharing product data and processes.

There are multiple other IT tools available at each department. These tools have specific application areas depending on the task that they are used for, for example simulation tools. These tools are summarized and presented in Table 4.2.

Table 4.2: Table presenting the specific IT tools used at different ME departments at CEVT

Tool	Description	Department
AutoForm	Software for sheet metal forming used for stamp simulations.	Stamping
Catia	Software developed by Dassault Systèmes and is used for computer-aided design, manufacturing and engineering.	Biw, GEO, Paint
IPS	A math-based software tool used for verification of assembly feasibility, design of flexible components and ergonomic evaluations.	Paint, T&CF
Pam-Stamp	A stamping simulation software mostly used for thermoformed parts.	Stamping
Siemens Process Simulate	Software tool from Siemens used for manufacturing process verification in a 3D environment.	BiW, Paint

4.2.2 Virtual Reality at case company

At the time of the case study some advancements within the field of VR had been done at CEVT. The ME department has a room equipped with a VR setup that they can use. The VR setup is an HTC Vive HMD with two VR controllers. This room was set up by a few engineers from the T&CF department that saw a potential of using VR within their work. These are also the people that currently utilizes the VR setup most. The general level of knowledge of VR is however low at the ME department. The people that made the VR setup have the most knowledge about it and are working to share the knowledge to others at the ME department so that it can be utilized more. Even though some people use VR in their work process it is not stated in their work process descriptions as a tool to use for certain activities. A picture from the current room can be seen in Figure 4.3.

Figure 4.3: Current VR room at CEVT with HTC vive setup. (Authors' image)

4.2.3 Communication

CEVT is a Swedish company owned by a Chinese cooperation, which means that a lot of the communication is long-distance through several time zones to Chinese manufacturing partners. This puts a high demand on the type of communication. There is a technical need for fast and stable internet connection, reliable hardware on both sides and a well-functioning Skype connection. This is sometimes considered, by the interviewees, as a limitation for the employees in their long-distance communication with each other. It is perceived as difficult to communicate through screen sharing. Connected to this there is also a need for many business trips to China to enable easier discussions and ensure everyone understands and solves the same problem with the parts or processes. These trips are also necessary in the physical testing phase since there are several areas necessary to test in reality before ramping up production. Areas in need of testing are car crashes, perceived quality, assembly precision and production processes. There is however a desire to minimize these trips because of possible time and money savings.

The internal communication is today handled through emails and in different cross-functional meetings. Sometimes it is perceived, by the interviewees, that changes made to a concept is not communicated properly or missed. This issue is solved today by participating in meetings as audience to receive the necessary information. The cross-function meeting is a forum where changes to a part or process are discussed together with several different functions participating. During these meetings manufacturing challenges are discussed from several different perspectives since one change in one department affects others as well. The coordination of all changes is Research & Development (R&D) responsibility therefore it is important to have good communication so the importance of the issue is understood properly. Several departments wish for a way to simplify their communication barriers using other tools. A lot of communication is also done with internal colleagues from the same department. This is considered an easier communication since the people involved comes from the same discipline and are more closely related to the work.

The meetings most often take place in meeting rooms, but smaller discussions are common to have directly at a person's desk. The number of people attending the meetings can vary a lot, but the majority are under 5 people. Meetings through Skype are very common if someone cannot be present physically. If this is the case the screen is often shared so that everyone can see the same image. When presenting something during meetings it is mostly done by 2D images in the form of screenshots of the discussed problem with explaining text and graphics.

4.2.4 Challenges

ME works for checking the manufacturability of the car within different areas. When doing these checks there are several different occurring problems connected both to the product but also the work process of the engineers. The problems commonly faced can be categorized into: analysis, certification, communication, ergonomics, lack of information, IT, manufacturability and simulation limitation.

- **Analysis** of a simulation is described as a problem because functions to be analyzed are so small they cannot be visualized in a simulation. Another problem connected to analysis is when studying for example tool retraction, reachability and perceived quality. In these cases there is a need for physical testing to be able to analyze these problems. Analysis is a big category since all work tasks include some sort of analysis of a problem to be solved.

- The second category is **certification**. This was mentioned by the interviewees as a problem because right now there are laws and regulations, which demand for example car crash testing to be able to certify the car. Certification of the cars today demand testing in real life and it is not enough to verify it virtually. Laws and regulations are also different depending on if the car is produced in China or Europe and modifications need to be made to the car depending on what part of the world it is produced in.

- The third category is **communication** problems. Challenges with communication are for example language barriers and communication regarding decisions. Lack of decision making and the communication of the decisions influences the understanding of the actual problem. There are many different departments collaborating and people come from different backgrounds, which also influences their perspective on how to communicate.

- Another category is challenges regarding evaluating sustainable **ergonomics** for the operators. These types of problems are connected to analysis but are specific to if the person can perform the operation or not, if they can reach the wanted position within the ergonomic standard. The standards are however different between countries, which also needs to be considered.

- Another category is challenges related to a **lack of information**. These types of problems can be related to communication problems but are more specified to missing information of prerequisites, decisions, time plans, changes or that the information is outdated. These types of problems can be related to working outside of the set standards but also lacking in standards for certain work tasks.

- The limitations and challenges connected to the **IT** tools are expired licenses, slow internet connection influencing the quality of conversations through Skype and programs lagging due to high amount of data. This also has connection to the computer power needed for running simulations, which also is perceived as being a problem when running bigger simulations.

- Challenges connected to **manufacturability** are problems with producing and manufacturing the vehicle. It can be that something does not work in the car, construction problems, problems with material cracking or a need for increasing soundproof material. These types of problems are part of the work tasks for the ME departments to solve when evaluating if all parts of a car are possible to manufacture or not.

- The **limitations with the simulation** software are also a common challenge that is experienced. This means that the simulation software that are accessible today cannot simulate everything that is wanted. This problem makes decision making more difficult and unreliable. Coloring and back spring of material are examples of cases that cannot be simulated.

These eight categories were decided to be used in the mapping phase as areas of application for ME. Most activities performed at the ME department at the case company can be categorized into these areas.

4.3 Result from mapping

In this section the second research question is answered, what application opportunities there are between available VR technologies and ME processes. This section will present the result from the mapping of both VR and ME. Three matrices were created for this step. The most relevant information will be highlighted in this section and the full matrices with more detailed information can be seen in Appendix B.

4.3.1 High-level cross mapping

For the high-level cross mapping areas of application for VR were cross compared with areas of application for ME. The application areas for VR were identified through the literature study, presented in Section 2.6. The areas of application for ME were the eight categories identified through the case study data collection, presented in Section 4.2.4

Areas of application for VR:

- Communication
- Design
- Ergonomics
- Training
- Virtual assembly
- Visualization

Areas of application for ME:

- Analysis
- Certification
- Communication
- Ergonomics
- Information
- IT
- Manufacturability
- Simulation limit

In the high-level cross mapping, seen in Appendix B.1, two ME areas were removed as possible areas of application of VR. These two areas, IT and certification, were not supported by the areas of application for VR found in the literature study. The remaining ME areas were matched together into three different general areas: **analysis** (analysis and ergonomics), **communication** (communication and information) and **visualization** (manufacturability and simulation limit).

4.3.2 Exploring activities

In the second mapping phase a deeper research of activities at the case company was performed. In total 17 potential activities suitable for VR were found within the three areas. The activities were appointed a category. The activities may overlap between areas but were categorized for structural purposes. More detailed explanations of the activities can be seen in Appendix B.2.

Analysis:

- Assembly geometry assurance
- Ensure safety of operator
- Equipment verification
- Ergonomics
- Reachability
- Study processes

Communication:

- Claim support
- Collaboration
- Create work instructions
- Discussions
- Meetings
- Status reporting

Visualization:

- Concept verification
- Experience cell layout
- Experience factory layout
- Experience line layout
- Perceived quality

4.3.3 Identifications of combination

Each activity was appointed a recommended HMD and set of peripherals. The HMD and peripherals used for the recommendations were found in Section 2.3.4 and 2.4 and are presented here:

- High resolution HMD
- High FOV HMD
- VR controller
- Motion tracking
- Haptic feedback
- Eye tracking
- VR motion platform
- Eye tracking
- VR motion platform

The full matrix with all the combinations can be seen in Appendix B.3. It was found that most of the activities could be used with standard VR equipment that is available today at the case company. These activities could therefore be implemented today. The other activities that required extra equipment were set to be able to implement within one year or later since the equipment is not currently available at the case company. There was no activity that required eye tracking or a VR motion platform, which led to them not being in the matrix. For some of the activities two combinations of HMD and peripherals were recommended. One combination was done for the minimum requirement of the VR equipment to be able to perform the activity. This combination would be enough to perform the activity and this implementation can be done earlier. The other combination was recommended with additional equipment to have an increased output level of the activity but would delay the time span of implementation.

4.4 Physical testing

In this section the result from the test and survey is presented and the hypotheses, from Section 3.4.1, are answered. This is used a base for validating the found application opportunities, presented in Section 4.3. All the answers to the questionnaire are not presented in this section but the full questionnaire with answers can be seen in Appendix C.

4.4.1 Desktop vs. Virtual Reality

In total 13 people, 22% of the ME department, took part in the test. The distribution varied from two to four people from each ME department. The majority of the test persons matched the designed test person profile and none of the test persons had previously used VR for their work tasks at CEVT. It was not possible to only include manufacturing engineers or simulation engineers due to unavailability. This meant that people who had other positions also participated in the test.

The first hypothesis for the test was that "VR is preferred compared to a regular desktop". Based on the answers from the questions relevant to this hypothesis it can be seen that most of the test persons either prefer VR or wants to use VR in combination with a regular desktop setup. None of the test persons chose only to use desktop for explaining tasks and problems and a majority voted for VR as the preferred option. A majority of the test persons also voted for VR as a better method for visualization. When making decisions a majority voted for the use of both VR and desktop. These results can be seen in Figure 4.4. Based on these answers it can be said that overall the hypothesis is false but correct in explaining and visualization.

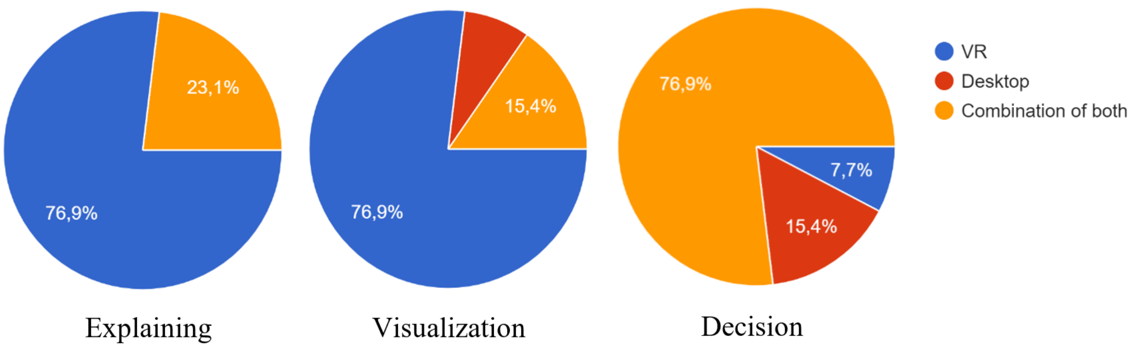

Figure 4.4: Result desktop vs. VR

A majority of the test persons did not feel any symptoms of motion sickness but there were some persons that did feel motion sickness in different degrees. One person answered that she/he was close to being stomach sick. The general experience of being in immersed in the virtual environment was positive among all the test persons expect for one whom had a neutral experience. From direct observations it was possible to see that some people had problems using the controllers and to interact with the environment. This problem was more present in the beginning of the test and the test persons got more comfortable with the technology over the duration of the test. Many of the test persons also mentioned that haptic feedback when colliding with objects would be an improvement to the user experience.

4.4.2 Estimated changes

The second hypothesis stated the estimation of changes that an implementation of VR in the found activities would have. The hypothesis had three parts connected to: quality, time/cost and user experience. These parts are the evaluated improvement factors. The first part of the second hypothesis stated that in overall the quality factor would be evaluated to “Great improvement”. From the survey it can be seen that in general the quality varies between "Improvement" and "Great improvement". The hypothesis was therefore wrong, but the survey still shows that it was close to the hypothesis. Meetings and experience factory layout were the activities which received the most votes, i.e. eight, on "Great improvement" in the quality factor. The second part in this hypothesis was that time/cost would be evaluated to "Improvement". This hypothesis is confirmed since in nine of the activities "Improvement" has the most votes. The last part of this hypothesis was that the user experience would be evaluated to "Improvement". This part of the hypothesis can also be said to be confirmed since "Improvement" has the most votes in twelve of the activities. Experience factory layout was the application area that received the most votes on "Great improvement" in the user experience factor.

The survey was also used to evaluate the 17 found activities from the mapping. Almost every activity had a majority of the votes in "Improvement" and "Great improvement" in the evaluated factors. The only exception to this was the time/cost factor in status reporting. There were also some activities which had results that stood out from the other and these can be seen in Figure 4.5. Ergonomics and concept verification received only one vote that was not "Improvement" or "Great improvement". Claim support, ergonomics and work instructions received only "improvement" or "Great improvement" in quality and user experience. The activity that was rated lowest was status reporting. In this area "No change" was the most voted category in all of the factors.

Figure 4.5: Estimated changes for the activities: ergonomics, claim support, concept verification and status reporting

4.4.3 Evaluating importance of different factors

The third hypothesis was that "When evaluating factors time is considered the most important, and communication is the area which is believed to be the most beneficial activity to implement VR in". From the survey it can be seen that the most important factor in general was quality. Quality was also the most voted factor within the three different application areas: analysis, communication and visualization. Though, an increase in votes for low time consumption and user experience could be seen in visualization and communication. The most beneficial area to implement VR in was believed to be visualization. From direct observation during the tests it could be noted that many of the test persons commented about visualization as a tool for easier communication. However, based on the survey the third hypothesis is false.

4.4.4 Use of VR in work processes

The last hypothesis was that "VR is believed to be a tool to utilize". This hypothesis is confirmed based on that almost every one of the test persons thought that VR could be utilized in their work today. Further, it can also be seen that almost every test person saw potential benefits with VR within analysis, communication and visualization. It was also found that the most common concern regarding VR is that the test persons do not know how to implement it in their work tasks.

Based on the mapping and testing, final recommendations and guidelines were given to the case company to explain how they should work with VR in the future, this is presented in Appendix D.

5
Discussion

The structure of the discussion is based on the research question, purpose and aim of the thesis. Section 5.1 discusses the first research question and the first aim. The second research question and the second aim are covered and discussed in 5.2. Lastly, the result's impact on sustainability is discussed in Section 5.3.

5.1 Evaluation method

The developed evaluation method is an overall method, which might be applicable for other technologies and companies as well. The developed method is based on previously developed methods and tools. Through the case study this method was applied. The three major steps of the evaluation method are all founded on other methods and theories. When combining methods with theories and verifying the developed evaluation method through the case study it contributed to the continued research and development within manufacturing engineering.

Through the data collection in the first step of the evaluation method both information about the technology and the possible application opportunities within the company is gathered. The multiple uses of sources cover different perspectives. For the case study data collection four different sources are used based on the six sources of evidence described by Yin (2014). From the implementation of the evaluation method at the case company it was perceived that the two excluded sources, archival records and physical artifacts, were not relevant. Even in other cases the possible information from these sources are not likely to produce any beneficial information in understanding possible application areas. According to Yin (2014) the interviews is one of the most important sources of information when performing a case study and this was also true for this case study. The information gathered from the interviews made it possible to understand how to further investigate different areas with the help of the three other sources of evidence. Since a lot of the research of the case company was based on the interviews it would have been beneficial to interview even more people to get other perspectives of for example challenges and communication issues. However, the actual interviews covered all different type of relevant profiles at the ME department, which was enough for finding possible application areas in this case.

When doing the mapping, in the second step, the generated matrices give a clear overview of the evaluated technology and especially the activities and application areas where the technology possibly can be used. This overview serves an important component for understanding and structuring the research. The comparison of the two different data sets, included in the mapping (application areas and the technology's application areas), creates a possibility to identify application opportunities. It also removes data that is no longer relevant, which further makes the research easier to understand.

In the final step, when doing the validation through a physical test, it is possible to validate the found application opportunities. In this validation phase the company also has the possibility to understand the level of knowledge of their employees. When doing the physical testing 13 people participated in the test, which represents approximately 22% of the workforce at ME. When studying the responses, a trend in the answers can be spotted in almost all questions, this indicates that the number of test people were enough. However, if more people would have participated the data validity had been greater and the spread of VR knowledge at the case company would have been wider. If participants with knowledge of VR would have been allowed to take part in the test, it would probably have influenced the result. For example, they might have focused on comparing how they work with VR instead of comparing it to the desktop setup.

The evaluation method has a possibility to be used in other instances where new technologies are evaluated. How far from the automotive industry the method might be used is hard to state since the case study was made in that particular industry. There is however a possibility that it can be used in other industries as well, for example within healthcare industry and education. Since no part of the evaluation method is connected exclusively to a particular field within the automotive industry there is a potential for an increased application area of the method. The evaluation method worked well for the case company and it would be interesting to apply it for other technologies and other companies to further study the usability of the method.

5.2 Application areas

The three found areas of application for VR were analysis, communication and visualization. All the categories are somewhat intertwined and in regards to which activities were categorized into which category it was hard to find distinct differences. This might also be the hardest part of the method to reproduce since other researchers might find other categories and activities or categorize them in a different way. However, the principle of the function of the different categories is to understand where the greatest potential of VR lies, which the found application areas indicated. Another purpose of the categories was to understand where VR might not be suitable to implement. Certification was one of the two areas that did not match with any of the areas of application for VR. Certification today is connected to physical testing and cannot be replaced by a virtual test. In the future this might be a possibility, but laws and regulations need to be changed for the certification to be valid for virtual concepts as well. If a virtual concept would be enough for certification there would be no need for a actual physical build before ramping up production. This would probably save a lot of time and reduce major costs.

By following the created method, in total 17 activities to apply VR in were found and validated through the physical testing. The found activities were based on both the literature study and case study, which gives the findings good credibility. The credibility is further increased by the result from the validation where it could be seen that implementing VR in the found activities was considered to provide improvements. Even though status reporting was the lowest rated activity in the survey it is still included as an application opportunity for VR. One reason this activity was the lowest rated is probably because of the standard way that it is performed today, and that people feel confident in how the activity is structured and performed. This might lead to that it is perceived as non-beneficial or difficult to change the standard way of working if implementing VR in the activity.

Regarding the questions in the survey, about which method the test person felt most confident in basing their decision or recommendation on, there was a large difference between explaining, visualization and decision making. Regarding explanation and visualization, VR was perceived as the easiest to use, while for decision making most people would prefer a combination of VR and desktop. This showed that VR should not replace the current way of working with a desktop but instead be used as a complementary tool to improve the analysis in the ME processes. Though as the VR technology evolves, this may change. In the future, problem solving will most likely be very different. When the use and number of virtual models increase there will also be a bigger need for virtual tools, such as VR. The problems solved today might not even be discussed in the future because they will already be solved, for example maybe with the use of artificial intelligence.

The 17 activities were categorized into analysis, communication and visualization. The result from the survey showed that visualization was believed to be an area where it would be most beneficial to implement VR in. The first impression when using the HMD was most likely the visual difference compared to looking at a two-dimensional screen on a traditional desktop. This first impression may have affected the result of the questions regarding visualization. The impact on the result were probably minimised since the test demonstrated different use cases of VR. This result from the testing is also in correlation with the first mapping phase where visualization was the highest rated of the three areas, can be seen in Appendix B.1. Both analysis and communication also need visualization in some sense to be able to study the problem being analyzed or discussed. Akpan and Shanker (2017) confirm that visualization in scale 1:1 is advantageous for performing analyses and that using the VR tool for presentations is beneficial. This statement confirms that the three application areas are well connected, and that visualization is a part of the other two areas (analysis and communication). This is probably why visualization is considered the greatest area of implementation of VR.

Based on the result from the survey, a trend can be seen that all the evaluated improvement factors are showing potential to be improved. User experience did not receive any votes below "No change". The reason for this may be because the way you use VR technology is very different from a traditional desktop. The change in methods will give variation to the work, which probably is seen as a positive aspect. The motion sickness is a drawback of VR regarding user experience but from the market research it could be seen that there is development to minimize this. One reason the first part of the second hypothesis, concerning the quality of the activity, was not correct is probably because VR today cannot produce all the information that a regular desktop can. The quality factor is still rated high, which is very important since quality was the factor that was voted the most important factor.

5.3 Sustainability

Based on the findings from the research there are potential benefits within all three areas of sustainability: environmental, social and economic. Since the demand for sustainable manufacturing has increased, according to Stoycheva et al. (2018), this raises the relevancy of the result and its contribution to the research within the area. The implementation of VR technologies can support and improve the environmental sustainability. The improved quality in the ME processes will give better solutions to implement in the manufacturing facilities and improve the quality of the products that are produced. This means that there will be less parts that will be scrapped, reducing the material and energy waste. By increasing the amount of ME process steps that can be done virtually, the need to manufacture physical prototypes will be reduced, which will further save material and energy. Improved quality of the ME will also increase the efficiency of the manufacturing facilities, using less energy per produced car. Instead of travelling to the manufacturing facilities, as it is done today, some of the trips may not be necessary or can be replaced by using VR. This is also mentioned by Fast-Berglund et al. (2018) and (Lawson et al., 2016) as a benefit of VR. Fewer trips from Sweden to the manufacturing facilities in China can lead to reduced CO_2 emissions.

The result also shows that the social sustainability can be improved since the use of VR technologies make it possible to test work stations from the view of the operator. Ergonomics can be evaluated more realistically by performing the task in VR. Harmful tasks can therefore be discovered more easily and changed before they are implemented. This can prevent injuries and make the work environment safer and more sustainable for the operators. This will also positively affect the economic sustainability since sick or injured employees are very costly. From the survey it can be seen that user experience is considered to be improved with an implementation of VR technologies in the activities. The social sustainability could therefore be increased by the improved user experience.

The economic sustainability can also be improved since the results shows that applying VR to the ME processes has potential to reduce the time and cost needed to perform the identified application opportunities. The quality factors also shows potential improvements from implementing VR, which also is stated by Lawson et al. (2016) and Seth et al. (2008). With improved quality better results and less errors in ME processes will occur. A reduction in the amount of errors will produce less rework, which can be a very expensive part in a production development process. By improving the ME, the manufacturing facilities will become more efficient reducing the cost for each car that is produced.

6
Conclusion

The method for evaluation was developed and validated through the case study. The method for evaluating possible application areas for new technologies follows three major steps. The first step being two types of data collection, the second step is a mapping phase of the findings and the final step is a validation of the result from the mapping through a physical testing. This evaluation method can be used for other instances as well when areas of application for new technologies are to be found.

Three areas of application for VR technology were discovered through the case study. These areas are analysis, communication and visualization. It is in these areas where the greatest potential lies for the case company to benefit the most from the technology if implementing it here. Within these three areas 17 activities were identified at the case company that had the possibility to be improved with an implementation of VR. VR should however not replace the current way of working with a desktop but instead be used as complementary tool to improve the ME processes. The recommendation for the case company is to firstly start using VR as an aid for enabling better communication and ergonomic evaluations.

From the result and discussion, it could also be seen that the sustainability would be improved from the findings in the thesis meaning that the purpose of the thesis is fulfilled. Future areas of research are to implement VR into the activities and study the effects of them within cost, quality, time and user experience. Further research could be to use the evaluation method at other companies or to evaluate other technologies.

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A

Case Study Data

In this appendix the following sections can be found:

A.1 Overview of work tasks

Department	Position	Purpose	Classification	Time consumption	Visualization most important
BiW	SIM	Make sure the product is able to be manufactured		Feasibility check	
BiW	SM	To create an efficient way of working		Discussing with IT Planning	
BiW	SM	That the product is manufacturable		Analysis	Communication R&D
BiW	SPL	Solving problem related to the manufacturability of the car		Solving issues with the team	
GEO	ME Geometry	Make sure that they can build the product they have in mind.		Meetings, Feedback to DM	
GEO	Temp. direc	Solve, create a process and ensure that the composition works.		Communication and discussions with R&D. Writing PRI to make problems visual.	
Paint	Catia Engineer	Keeping system updated		Doing changes in Catia and and updating BOM in Teamcenter	
Paint	Director				
Paint	ME/SIM	Ensuring that it is manufacturable		Preparation of simulation Analyses	Describing a problem
Stamping	ME Stamp	Solving manufacturing problems with articles that R&D creates. Controlling that they are possible to manufacture in a good way		Simulation of articles	Making sure R&D understands changes
Stamping	SM	Make the articles able to produce, solve problems early before production		Creating the processes in the simulation software(Autoform).	Communication to customer, see where the problem is
TCF	ME Powertrain	To have the view of the operator		P-FMEA, instructions and tools requirements	Reality perception
TCF	SIM	Help ME understand complex assemblies and do more advanced simulation		Simulations, and doing presentations to ME that they can use for presenting to R&D	See surroundings
TCF	SM	Suport the ME when they encounter problems with their work.		Search for information and sort it.	Not in his work
TCF	SPL	To watch over the bigger picture, holistic point of view over TCF		Focuses on the technical work and not the administrative.	Communication

Classes

Classification	Description
Communication	Working mainly with issues regarding work process at CEVT and assisting colleagues
Manufacturability	Working mainly with issues regarding manufacturability of the concept

Comments

In this map an overview of each interviews purpose, most time consuming task and where they find visualization most important presented.

The classification is connected to the persons described purpose and is used as for understanding what perspective the people have.

A.2 Overview of positions at departments

			Positions					
Departments	**Number of people**	**Main task**	**Director**	**SM**	**SPL**	**ME**	**SIM**	**Other**
BiW	16	To make sure that the product is feasible for the manufacturing point of view						Welding expert
GEO	8	Ensure that it is possible to build the car geometrically within the limits of the tolerances.						Dimensional Management Engineer
Painting	6	Construction and ME department						
Stamping	7	To develop articles that can be produced for the cars						
TCF	30 +	Clear work instruction for how to produce the car. Give input to R&D during the development phase.						

Abbreviations	
SM	System Manager
SPL	System Project Leader
ME	Manufacturing Engineer
SIM	Simulation Engineer

Comments

This map shows the different functions at the departments. The number of people differ from time to time but gives an indication of the size of each department.

A.3 IT tools

Department	Position	PS	IPS	AutoForm/ PentStamp	Catia	Process designer	CD4 (measure database)
BiW	SM						
BiW	SPL						
BiW	SM				Visualization		
BiW	SIM	Simulation					
GEO	Temp. direc						
GEO	ME Geometry						
Paint	Director						
Paint	ME/SIM	Geometry of station	Simulation		Centerlines		
Paint	Catia Engineer		Simulation of operator		Changes		
Stamping	SM			Simulation			
Stamping	ME Stamp			Simulation			
TCF	SM						
TCF	ME Powertrain		Simulation				
TCF	SIM		Simulation				
TCF	SPL						

Comments
All departments uses: Team center (+ visual mock-up), Office packages, Skype, SharePoint

A.4 Communication

Department	Position	Collaboration	Presentation tools	No. people	Location
BiW	SM	GEO R&D	Powerpoint Picture Process Simulate	3-5	Meeting rooms
BiW	SPL	The team	Powerpoint	6-10	Meeting rooms Skype
BiW	SM	R&D ME colleagues ME	Powerpoint	2-10	Meeting rooms
BiW	SIM	Project leaders ME R&D	ECR (Excel)	2-6	Meeting rooms Desk Skype
Paint	Director		Screen Powerpoint		
Paint	ME/SIM	ME colleagues Paint team	Skype, Powerpoint Powerpoint	Approx. 3	Office Skype
Paint	Catia Engineer	R&D BiW	ME change requests PCR	3-4	Meeting rooms Skype
GEO	Temp. direc	BiW Dimension Management R&D	Pictures Product Related Issue (PRI) with R&D	1, meeting can be 10	Chats Skype Meeting rooms
GEO	ME Geometry	TCF PSS	Powerpoint	3-5	Meeting rooms
Stamping	SM	ME colleagues Project leader	ECR Simulation report Process plan	Alone, meetings 4-5, discussion 1-3	Skype and screen sharing
Stamping	ME Stamp	People in the department, Project leader Simulations go direct to R&D	Excel, Verbally (Body language)	1 person, sometimes more at engineering meetings	Own computer R&D
TCF	SM	Colleagues at Exterior SPL R&D	SharePoint	5-8	Meeting rooms, Skype
TCF	ME Powertrain	R&D equivalent Volvo equivalent	Outlook Skype	1-2	Meeting rooms
TCF	SIM	Helping colleagues with IT tools		1-10	Meeting rooms
TCF	SPL	Vehicle Integration SM and UPL in ME	VR Powerpoint	4. Not more when using VR.	VR room

Conclusions from map	
Summary of the map	
Collaboration	R&D and Internal colleagues keeps coming up a lot.
Presentation tools	Presenting with 2D imaging is most common
No of people	Span from 1-10 people. Majority is under 5 people
Location	Meeting rooms and Skype are most common locations

A.5 Challenges

Department	Position	Common challenges	Classification of challenges	Physical challenges	Classification of challenges
BiW	SM	System errors	IT	Springback	Simulation Limit
				Car crash	Certification
BiW	SPL	Technical difficulties, something doesn't work in the car	Manufacturability	Hardware test in design phase, especially joining	Simulation Limit
		IT issues	IT	Ergonomic issues	Ergonomics
		Communication skype	IT		
		Communication language	Communication		
BiW	SM	Lack of prerequisites	Information		
BiW	SIM	Design iterations	Information	Tool retraction	Analysis
		Decisions in R&D	Information		
GEO	Temp. direc	Making assessments of a solution	Analysis	Complex and complicated solutions (want to look & feel)	Simulation Limit
GEO	ME Geometry	Communication	Communication	Overslam	Simulation Limit
		Timeplans	Information	Wrapping	Simulation Limit
Paint	Director	Construction problems	Manufacturability	Coloring	Simulation Limit
		Increase soundproofing material	Manufacturability		
Paint	ME/SIM	Computer power	IT	Fixturing for holding cars	Analysis
Paint	Catia Engineer	Changes made by BiW	Information	Operators position	Ergonomics
				Reachability	Analysis
Stamping	SM	Cracks/thinnings	Manufacturability	Surface finish	Analysis
				Defects in shell parts	Simulation Limit
Stamping	ME Stamp	Simulated articles doesn't work	Manufacturability	Surface finish	Analysis
		Technical issues (licenses etc)	IT		
TCF	SM	Communication	Communication		
		Old information	Information		
		Lack of decisions	Communication		
TCF	ME Powertrain	Demand of new work procedures	Manufacturability	Changes affecting other changes	Analysis
TCF	SIM	People forgetting knowledge	Communication	Torque	Simulation Limit
				Lack of information from supplier	Information
TCF	SPL	Trying to understand the actual problem	Communication	Parts doesn't behave as in CAD, forces are a factor in reality	Simulation Limit
			Information		

Classes

Classification	Description
Analysis	Hard to analyze problem for example studying the simulation result
Certification	Necessary for certification of the vehicle, such as car crash testing
Communication	Challenges connected to communication
Ergonomics	Ergonomic issues for manual work
Information	Lack of information about changes/updates, for example from R&D or other departments
IT	Challenges with technical issues such as programs lagging, licences, bad connection
Manufacturability	Difficulties with parts (fitting in the car or being manufacturable)
Simulation Limit	Can't be simulated due to limitations or lack of programs

Comments

This map show the challenges explained by the interviewees. The classification was created by finding similarities in the described challenges.

This classification is used for "VR and applications" map and also for the "high level cross mapping"

A.6 VR and applications

Department	Position	Previous knowledge	User experience	Problem avoided	Application wishes	Other
BiW	SM	A lot			Discussing and status reporting.	Seeing in scale 1: 1
BiW	SPL	Have tried it			Presentation	Preparation time may be too long
					Visualization	
BiW	SM	Tested at TCF.	Good experience	Answer to conceptual questions	Get the line in a virtual environment	BiW will use VR for visualization.
BiW	SIM	Have tried it	Good experience	Tool fitting in the lines	Ergonomic studies	Data output and input needs to be easy for him to use it
Paint	Director	Yes			Communicating with China	
					Visualizing	
					Reachability	
					Looking at seams	
Paint	ME/SIM	Have tried it	Realistic feeling		Communicating with China	Wishes to utilize point clouds.
					Help with decision making	
					Experience different heights	
					See workplace layout.	
Paint	Catia Engineer	Have tried it	Felt dizzy afterwards	Visualization of getting in to the car	See the plant layout and go through processes to see possible errors	Most difficult part is to look into the interior parts
GEO	Temp. direc	None		For new concepts	Supporting what he claims	
GEO	ME Geometry	Have tried it	Good	Ergonomics	Visualization for discussions	Would like to see rendering between lamp and color
			Bad resolution and graphics	Assembly	Possible to see quality	
			Adds immersion and perspective			

Department	Position	Previous knowledge	User experience	Problem avoided	Application wishes	Other
Stamping	SM	Have tried it Done some testing but did not achieve the wanted result	Okey, nice with larger picture of object	Collision between tool parts Wrinkles Feeling for how it will look	Working remotely Visualizing in early phase	The technology needs to improved.
Stamping	ME Stamp	Have some experience	Bad resolution Dizziness	Surface finish (if possible to visualize)	Reduce travelling to see the tools (But this is not done by stamping)	
TCF	SM	A lot	Feels good for short amount of time, 15 min	Be able to see different tolerances	Ergonomics Look at problems together	He advocates AR.
TCF	ME Powertrain	A lot	No side effects Believes you get familiar with it	Able to evaluate tight spaces	Not having to travel Work together in virtual environment How well things fits Check product virtually Check necessary equipment	IPS have implemented VR and CEVT has a good dialogue with IPS, they put demands on them which IPS tries to implement in the software.
TCF	SIM	Yes	The more you use the more comfortable you get	Torque Verification	Easier explanation to R&D to reduce meetings	Do not need great resolution, interaction is needed, taking pictures and creating simulations, more useful in early phase
TCF	SPL	Yes	Annoying ads Lag Not made for industry use	Reachability	Reduce time for testing Testing of concepts	

Classes

Classification	Description
Analysis	Hard to analyze problem for example studying the simulation result
Certification	Necessary for certification of the vehicle, such as car crash testing
Communication	Challenges connected to communication
Ergonomics	Ergonomic issues for manual work
Information	Lack of information about changes/updates, for example from R&D or other departments
IT	Challenges with technical issues such as programs lagging, licences, bad connection
Manufacturability	Difficulties with parts (fitting in the car or being manufacturable)
Simulation Limit	Can't be simulated due to limitations or lack of programs
No class	No class suitable for the activity

Conclusions from map

Summary of the map

Previous knowledge	Almost everyone have some experience with VR
User experience	Most feel good when using VR but some feels dizziness. Many also comments on the addition of immersion
Application wishes	The wishes for applying VR is mostly to travel less, enable better communication with China and each other

Comments

This map presents the part of the interview surrounding VR, what previous knowledge and user experience the interviewee had. It also shows what problems they hope to avoid with the use of VR and which area they want it to be applied in. In the other columns other comments and ideas from the interviews are noted

The classification of the application wishes were made based on the classifications from the "Challenges" map and were used for inspiration for the "ideas for implementation" map.

A.7 Ideas for implementation

Idea	Area of use	Class	BiW	Paint	Stamp	GEO	TCF	Potential benefits	Potential problems	Potential user
Using VR to easier communicate and present changes in a Virtual Build Event meetings	Communication/ presentation		x	x	x	x	x	Time savings and savings in communication error, the meetings usually take 2-3 hours which potentially could be speeded up when using VR because it will simplify explanation	People not comfortable with VR Time consuming the first time Technology messing, delaying the presentation	Director, System Manager
Using VR to be able to do a Line walkthrough	Visualization		x	x				Doesn't need to travel there to understand the problem Saves time and money Go through the paint processes and see what could go wrong.	Set-up time vs. benefits	SM, ME
Discussing with R&D/PQ/DM about changes etc.	Instead of sharing screen through skype		x			x	x	Same as nr 2	Other person might not have VR Need for good visualisation quality	SPL
Test for reachability	Test feasibility of assembly		x	x			x	Less testing needed i real environment	Technology may not be available at CEVT now, hand tracking needed	ME, SIM
Point and explain what the problem is together in a VR environment	Communication, visualization		x	x			x	Less communication errors and no need to travel	VR multiplayer	ME, SIM
Seeing how the robot clashes with objects	Visualization		x	x			x	Easier to see a solution for the clashing problem	Time consuming or inconvenient to take on and off glasses and moving to other location	SIM
Testing how people of different sizes will reach	Feasibility of ergonomics			x			x	Less problems when testing in real life, better ergonomics	May need motion capture suit	ME, SIM
A support tool to backup what he claims	Communication, visualization					x	x	Supporting tool for discussions with for example R&D to be able to strengthen the decisions based on experience	VR multiplayer	ME, SIM, SM
Rendering	Visualization				x		x	Being able to see interaction between two parts in a virtual environment from different angles	Long setup time	ME
Discussions with China	Communication		x	x	x	x	x	Doesn't need to travel there to understand the problem Saves time and money	Other person might not have VR, bad quality of internet connection	All
Get a feeling for how it will look	Visualization		x		x		x	Se collisions between tool parts, wrinkles and feel 1:1 scale of how big parts are	Long setup time	SM, ME
Testing of concepts in early phase	Visualization		x				x	Reduce time needed for the testing and detect problems early before it goes to concept	Long setup time	SPL, SM

Classes

Classification	Description
Analysis	When the area of use is mostly connected to analysing ergonomic issues and other
Communication	When the area of use is mostly connected to enabling better communication
Visualization	When the area of use if mostly connected to issues regarding visualization

Comments

In this map all ideas that have come up, during interviews or simply when talking to people, are presented. These ideas were classified and marked which department they were applicable for. The potential benefits, problems and user were noted after discussions.

B

Mapping

In this appendix the following sections can be found:

B.1 High-level cross mapping

Areas of application for ME	Areas of application for VR: Communication	Design	Ergonomics	Training	Virtual assembly	Visualization	
Analysis	x	xxx	x	x	x	x	8
Certification							0
Communication	xxx	x	x	x	x	x	8
Ergonomics	x		xxx	x			5
Information	xx			x		x	4
IT							0
Manufacturability	x	xx	xx	x	xx	x	9
Simulation Limit	x	xx			x	xxx	7
	9	8	7	5	5	7	

Classes

Classification	Description
Analysis	Hard to analyze problem for example studying the simulation result
Certification	Necessary for certification of the vehicle, such as car crash testing
Communication	Problems connected to communication
Ergonomics	Ergonomic issues for manual work
Information	Lack of information about changes/updates, for example from R&D or other departments
IT	Problems with technical issues such as programs lagging, licences, bad connection
Manufacturability	Difficulties with parts (fitting in the car or being manufacturable)
Simulation Limit	Can't be simulated due to limitations or lack of programs

Conclusions from map

VR not applicable if value = 0

Certifiation	With certification issues there are more factors to consider (such as law regulations) which will need to be addressed before replacing/ adding activities with VR
IT	IT problems mostly need support from the IT department and VR is not seen as a useful tool to solve these problems

Joining of	Points	Comment
Analysis + Ergonomics = Analysis in next map	13	Joining of these two categories were made since ergonomic issues is a part of analysing problems
Communication + Information = Communication in next map	12	Joining of these two categories were made since information is a part of communication
Manufacturability + Simulation limits = Visualization in next map	16	Joining of these two categories were made because both categories are related to visualization problems

Comments

In this high level cross mapping identified areas of application of VR are cross compared with areas of application at the case company.

The 6 areas of application for VR are identified through the theoretical research and explained in more detail in the report.

The 8 areas of application within the case company are identified from the summary of the interviews. The classification is explained below.

When doing the cross mapping weight has been put on activities where the two areas are more applicable or give greater benefits, for example design and visualisation will impact simulation limits more than the other identified VR areas.

B.2 Exploring activities

Areas	Activities	Today *How is this activity performed today?*	Tools *What tools are used?*	Purpose *What is the purpose of the activity?*	Demands *What demands are there on the process?*
Analysis	Ergonomics	Evaluation of the operators ergonomic situation is today performed in different ways depending on department. TC&F is responsible for the assembly operations and have more concerns regarding the ergonomics of the operator. They use IPS for simulating ergonomics and also have an ergonomic expert available for consultation of different problems. Other departments base their ergonomics evaluation on experience. Some ergonomic problems are also discovered during testing and in production.	IPS Ergonomics expert Other simulation tools Experience	To ensure the operators working environment follows the ergonomic requirements that exist in different countries	Experience the operators view and feeling when executing operations Interaction with the environment
	Reachability	Reachability test of both human motion and robotic motion. Processes are evaluated through mainly simulation to check if the human or robot can reach the desired position without ergonomic issues or collisions.	Simulation software	Detect if a process is possible to perform or not	Visualization of work place Perspective of the operator or robot Manipulation and interaction with the environment
	Equipment verification	Verifying equipment is done through simulation and experience	Simulation software	Checking which equipment is needed for the manufacturing process and make a recommendation of the equipment needed in the factory	Good visualization of the accessibility of the equipment
	Study processes	Mainly done by the manufacture engineer when verifying the manufacturing processes	Simulation software	Checking the processes if they are possible to implement at the factory for the number of jobs requested	Good visualization of the processes
	Assembly geometry assurance	This task is mainly performed by TC&F. It is done through studying CAD parts and try to detect collision	Part of DPA5	The main purpose is to ensure that all parts can be assembled without clashes	Good visualization of all parts Clash detection
	Ensure safety of operator	Decisions are based on experience or the problems surrounding the operators safety are found in physical testing or in production	Experience	Purpose is to ensure the safety of the operator when performing certain tasks	Mannequin simulation Experience the operators view Clash detection

Communication	Meetings	There are two major type of meetings; in the same location and in different locations. The meetings are often cross functional and number of people participating are between 1-10, on average 5 people participates	Skype Powerpoint Simulation programs Simulation report	Inform and report status on projects. Enable interaction between people	More than one person visualizing a problem Good connection, when in different location
	Collaboration	All engineers collaborate frequently within the same projects but also in between departments	Teamcenter	Problem solving	More than one person visualizing a problem Quick and easy access to visualization
	Discussions	Discussions are mostly performed between departments regarding changes to concepts or product specifications.	Teamcenter	Exchange ideas and experience. Raise concerns regarding changes to a concept or product that might affect other departments	More than one person visualizing a problem Quick and easy access to visualization
	Claim support	Today most functions have some sort of simulation program to support their found solution. In some cases where there is no simulation or the result from the simulation is insufficient decisions and recommendations for concept changes are made based on experience. These decisions or demands on changes are hard to claim support for and are more questioned.	Simulation programs, experience	Support solutions to problems	More than one person visualizing a problem
	Status reporting	Reporting are done through an excel document where each decision and change are documented. The reporting follows a standard way of working and all departments follow this format of status reporting	PCR Excel	Informing and documenting changes made to a part	Clear documentation
	Create work instructions	When developing products to manufacture there is also a task regarding how the product should be manufactured. These work instructions are mostly explained through 2D imaging and in written format	PowerPoint Teamcenter	The purpose is to create instructions for operators to understand the manufacturing process	Clear instructions Easily understood

Areas	Activities	Today	Tools	Purpose	Demands
		How is this activity performed today?	*What tools are used?*	*What is the purpose of the activity?*	*What demands are there on the process?*
Visualization	Perceived quality	Analysing the perceived quality is a task mainly done through physical testing or based on experience	Experience Physical testing	Try to detect bad perceived quality before production	Good resolution Import of many files to see the whole product
	Concept verification	When verifying the concept several different processes are checked and verified. These verifications are made in every department on different parts of the product to ensure that the car is manufacturable	DPA5	Checking if the concept is possible to manufacture or what changes are necessary to do	Good communication between departments and R&D
	Experience factory layout	When needing to understand the plant layout drawings and point cloud scanning are studied, if these are available. Otherwise visits to the factories are made	Point cloud Drawings Factory visit	Understanding the layout of the factory can be necessary to understand which changes are possible to make or how big impact a new line or process are going to have on the surroundings	Visualize the whole factory
	Experience line layout	When trying to understand the line layout there are sometimes CAD files to study, or point cloud scanning. Otherwise visits to the factory are made.	Point cloud Drawings Factory visit	The purpose of understanding the line layout is to visualize possible changes and how these will affect the process. Also to make sure everything fit in the layout	Visualize the line Possible to import the concept for verification Getting a perspective of the size of components in the layout
	Experience cell layout	For the cell layout there are CAD files of how the cell will look like which can be studied to understand the layout	CAD files	The purpose is to understand the cell layout to be able to check that everything fit and what changes are possible to make	Visualize the cell Getting a perspective of how big or small parts are in comparison to the environment they are in

Comments

This map is based on the identified activities during the case study which have a possibility to implement VR within the three different categories; Analysis, Communication and Visualization.

First how they are performed today, which tools are used and the purpose of the activity. The demands on the process is a connection between what the activity demands and what demands can be put on the VR application.

These activities are used in "Identification of combinations ME vs. VR" map where the demands are used as a basis for the requirements specification on VR.

B.3 Identification of combinations

Areas	**Activities**	**Output level**	**Requirement specification on VR**					**What should be used?**	**Time span**
			What VR technology to use?					*What type of VR is suitable for this activity?*	*When can it be used at CEVT?*
			FOV	Resolution	Haptics	Motion tracking	Controller		
Analysis	Ergonomics	Minimum	Normal	Normal	None	None	Two	Normal HMD, controller	
		Additional	Large	Normal	Body, hands	Body, hands	None	Large FOV HMD, body suit, gloves and haptics	
	Reachability	Minimum	Normal	Normal	None	Body, hands	None	Normal HMD, motion tracking (body, hands)	
		Additional	Normal	Normal	Hands	Body, hands	None	Normal HMD, motion tracking (body, hands), haptics (hands)	
	Equipment verification	Minimum	Normal	Normal	None	None	One/two	Normal HMD, controller	
		Additional	Normal	Normal	Hands	None	One/two	Normal HMD, controller, haptics (hands)	
	Study processes		Normal	Normal	None	None	One/two	Normal HMD, controller	
	Assembly geometry assurance	Minimum	Normal	Normal	None	None	One/two	Normal HMD, controller	
		Additional	Normal	High	Hands	None	One/two	High res. HMD, haptics (hands), controller	
	Ensure safety of operator		Large	Normal	None	Body, hands	None	Large FOV HMD, body suit and gloves	
Communication	Meetings	Minimum	Normal	Normal	None	None	One/two	Normal HMD, controller	
		Additional	Multiple normal	Normal	None	Body	One/two	Multiple normal HMDs, controller, motion tracking (Body)	
	Collaboration	Minimum	Normal	Normal	None	None	One/two	Normal HMD, controller	
		Additional	Multiple normal	Normal	None	Body	One/two	Multiple normal HMDs, controller, motion tracking (Body)	
	Discussions	Minimum	Normal	Normal	None	None	One/two	Normal HMD, controller	
		Additional	Multiple normal	Normal	None	Body	One/two	Multiple normal HMDs, controller, motion tracking (Body)	
	Claim support		Normal	Normal	None	None	One/two	Normal HMD, controller	
	Status reporting		Normal	Normal	None	None	One/two	Normal HMD, controller	
	Create work instructions		Normal	Normal	None	Body	Two	Normal HMD, body suit, controllers	
Visualization	Perceived quality		Normal	High	None	None	One/two	High res HMD, controller	
	Concept verification		Normal	Normal	None	None	One/two	Normal HMD, controller	
	Experience factory layout		Large	Normal	None	None	One/two	Large FOV HMD, controller	
	Experience line layout		Large	Normal	None	None	One/two	Large FOV HMD, controller	
	Experience cell layout		Normal	Normal	None	None	One/two	Normal HMD, controller	

Evaluation levels

VR criterias	**Evaluation level**
FOV	Large (around 180 degrees)
	Normal (around 110 degrees)
Resolution	High (above 1400 x 1600 per eye)
	Normal (around 1080×1200 per eye)
Haptics	Body
	Hands
	None
Motion tracking	Body
	Hands
	None
Controller	One
	Two
	None

Time span

Direct, no major planning or budgeting is necessary, technology and knowledge excist within the company
Within 1 year, requires planning and some budget changes, investment may be required and a broader knowledge within the company is needed
Future, major reorganization and updating of work process description is needed. Deeper understanding is required, as well as technical knowledge. Technology needs to be developed before investment can be made

C
Physical testing survey

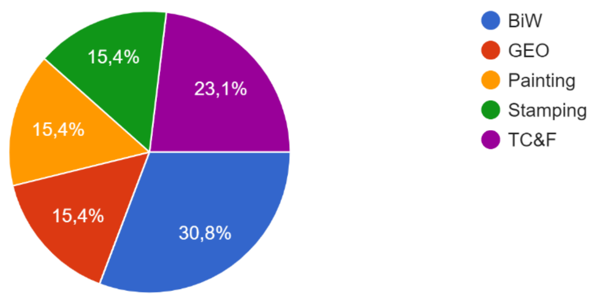
In this appendix the following sections can be found:

C.1 Preparation questions
C.2 Desktop vs Virtual Reality
C.3 Estimated changes
C.4 Evaluating importance of different factors
C.5 Use of VR in the work

C.1 Preparation questions

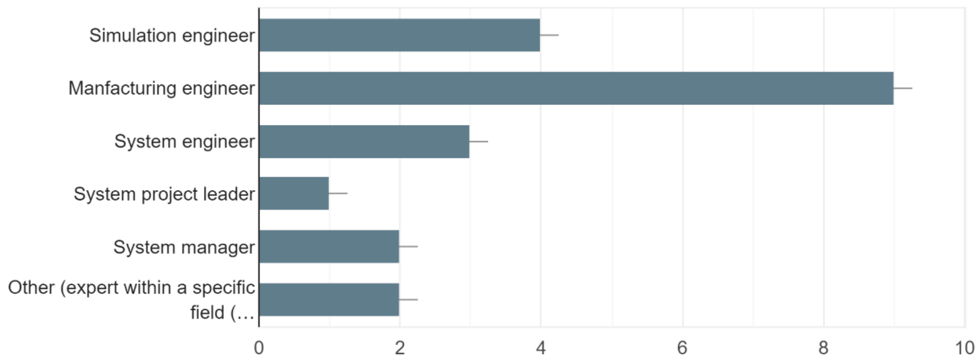
Which department are you from?

13 svar



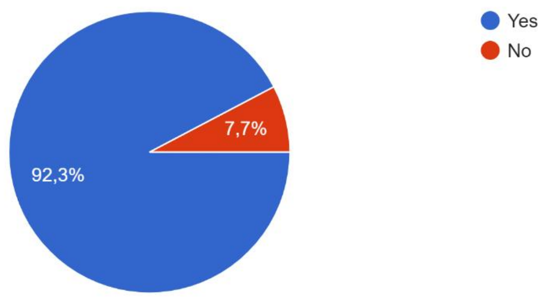
Which of these roles do you identify with? You may chose more than one.

13 svar



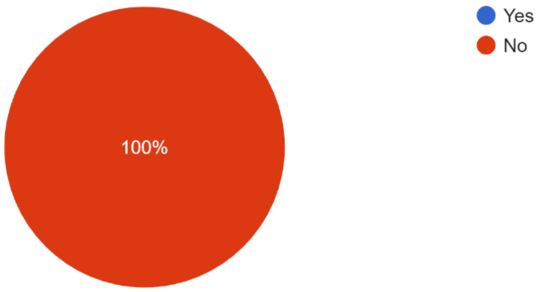
Have you tried VR at CEVT before?

13 svar



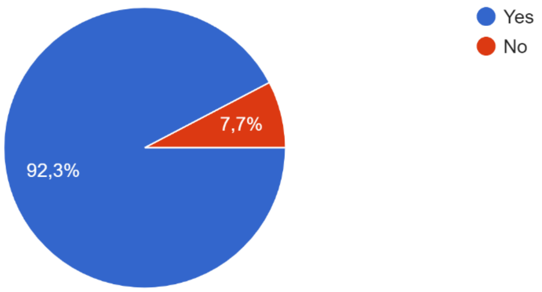
Have you used VR before in your work tasks at CEVT?

13 svar



Do we have your permission to take some photos during the test to possibly use in our report or presentations

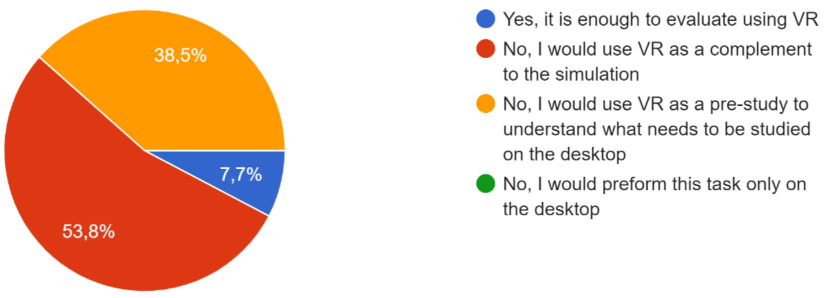
13 svar



C.2 Desktop vs. Virtual Reality

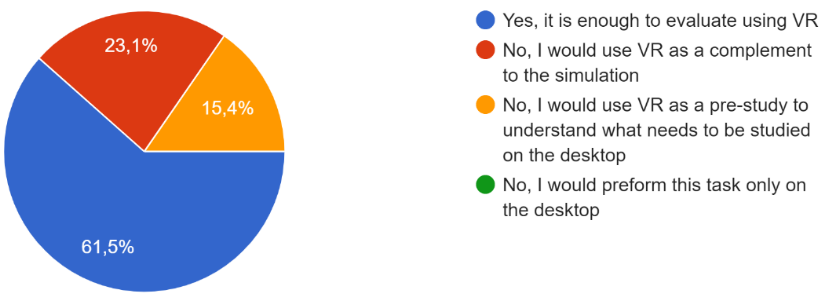
TEST 1: When doing a similar evaluation, is the output/result/information from the VR test enough?

13 svar



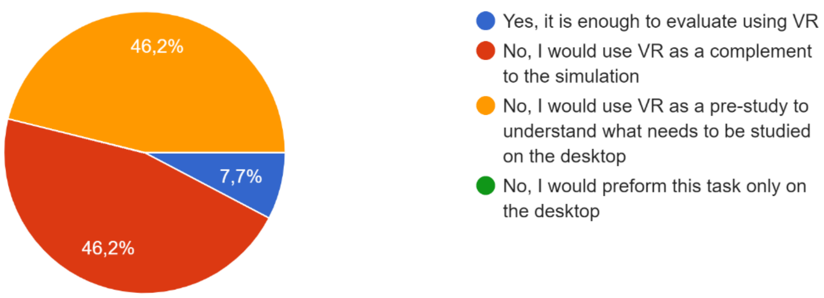
TEST 2: When doing a similar evaluation, is the output/result/information from the VR test enough?

13 svar



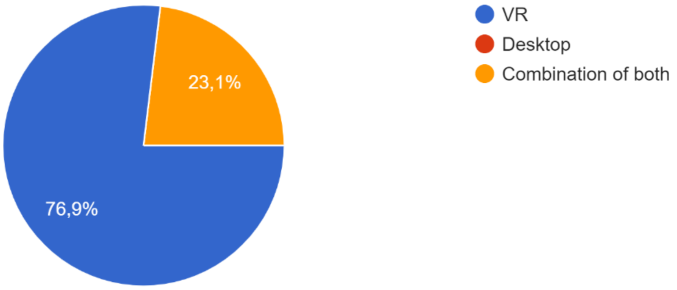
TEST 3: When doing a similar evaluation, is the output/result/information from the VR test enough?

13 svar



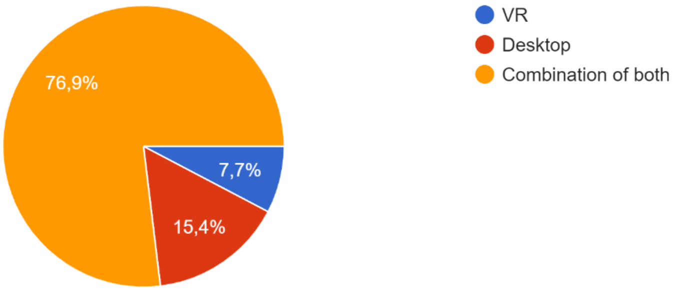
If you were to explain the tasks and problems to someone else, which method would be easiest to use?

13 svar



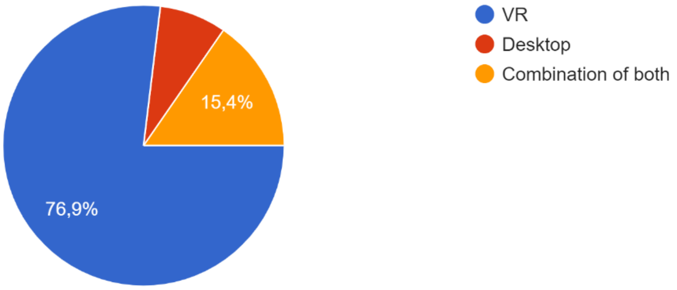
With which method do you feel MOST confident in basing your decision or recommendation on?

13 svar



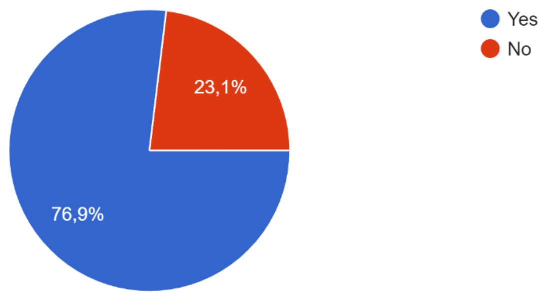
With which method did you get a better visualization of the tests?

13 svar



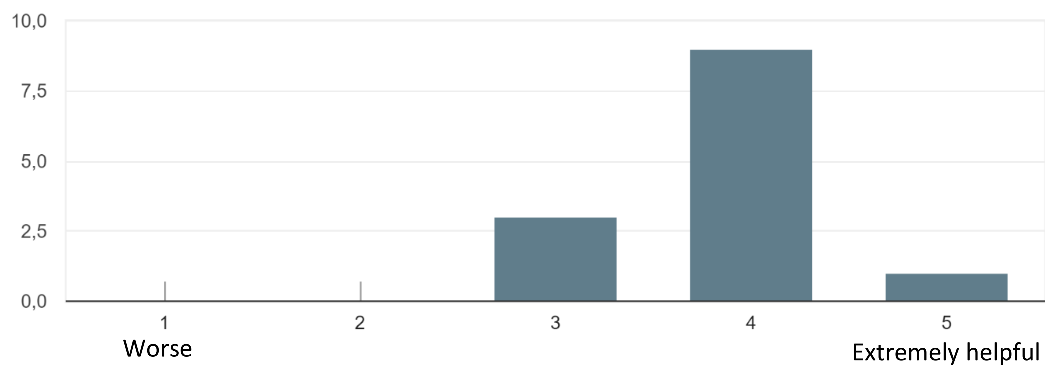
When preforming the tasks in VR did you reach the output/result/information you expected... to what you had seen in the videos?

13 svar



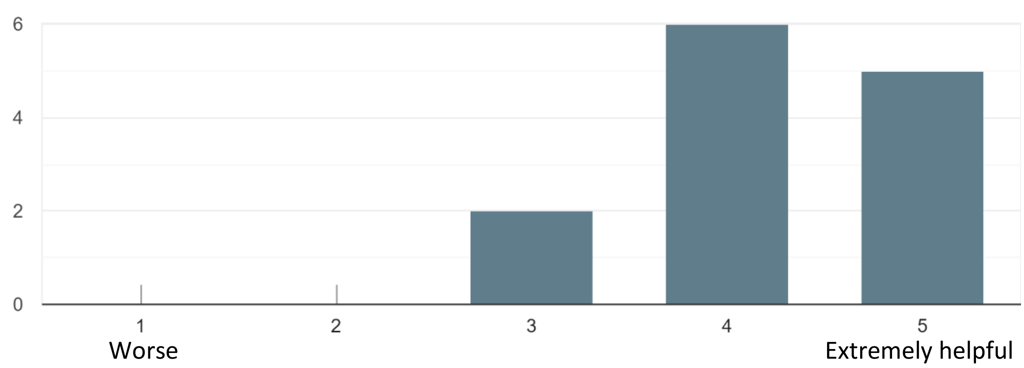
How did you perceive the precision changed when using VR compared to the desktop?

13 svar



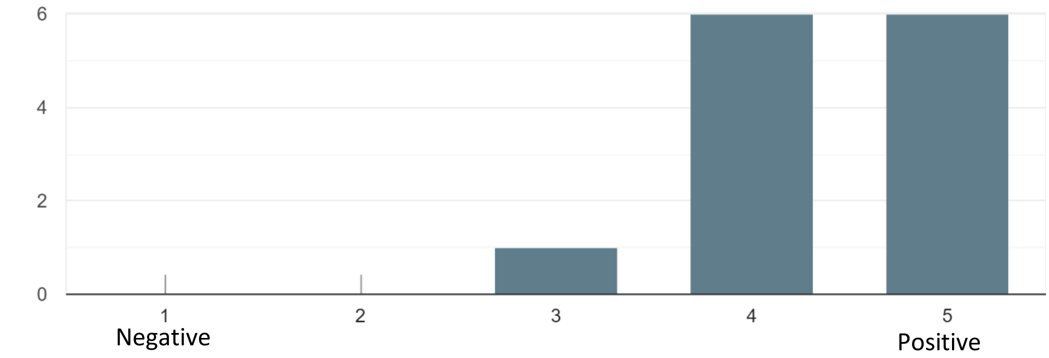
How did you perceive the visualization of the task changed when using VR compared to the desktop?

13 svar



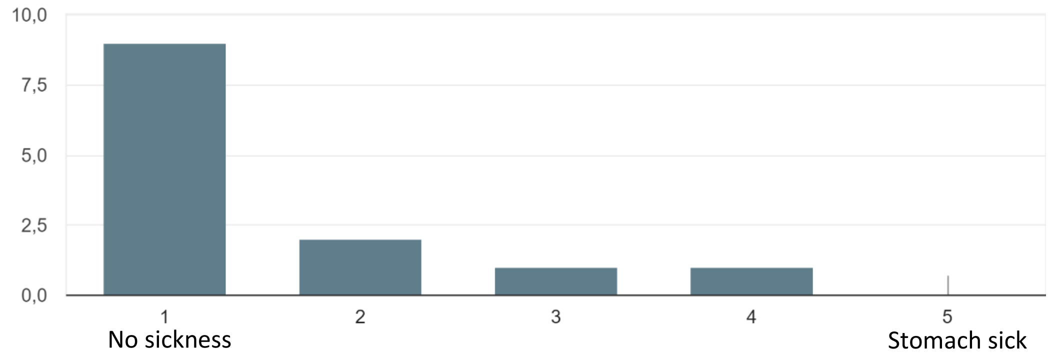
In general how was your experience in VR? How did you feel?

13 svar



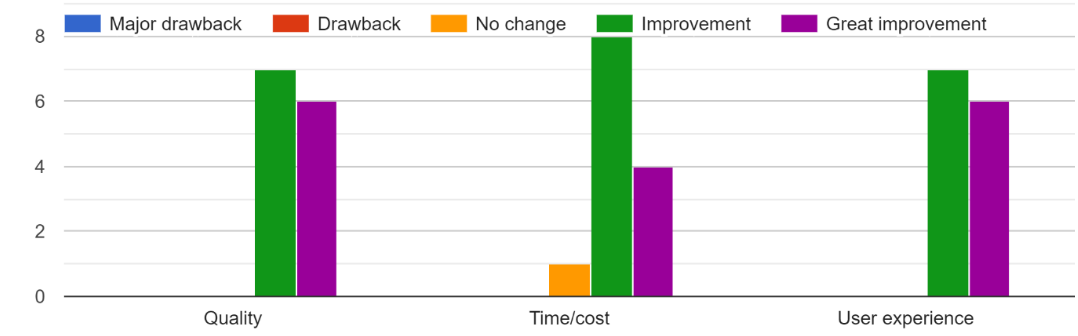
Did you feel motion sickness when wearing the HMD?

13 svar

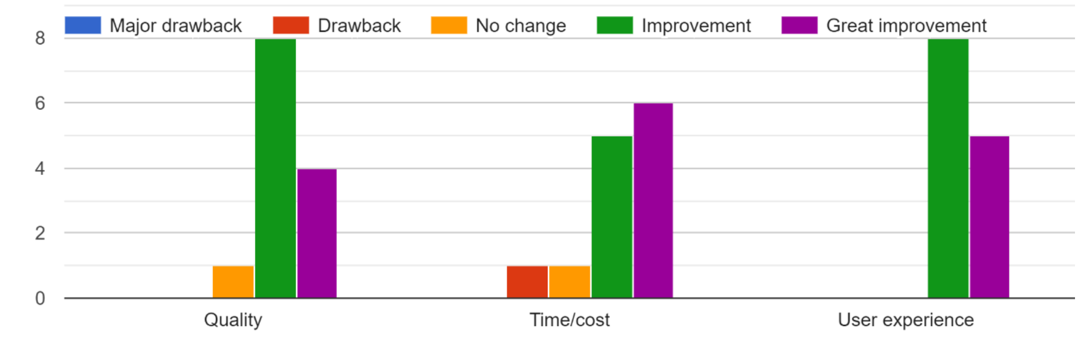


C.3 Estimated changes

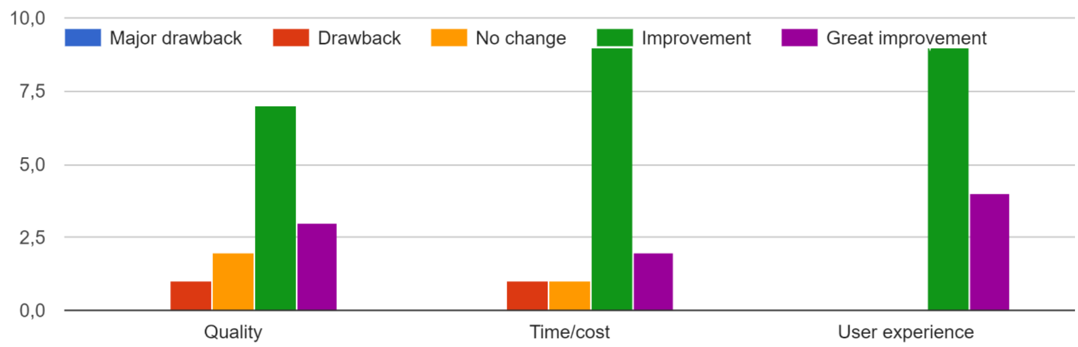
ERGONOMICS, evaluating operators ergonomic situation when preforming tasks



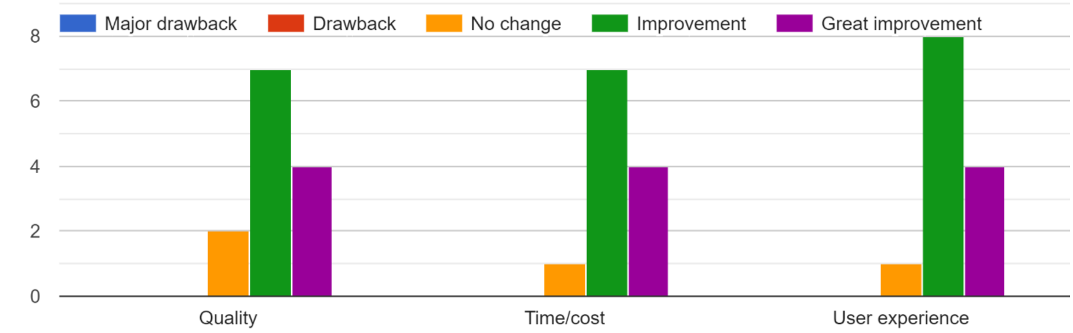
REACHABILITY, activity evaluating if the robot or operator reaches the position



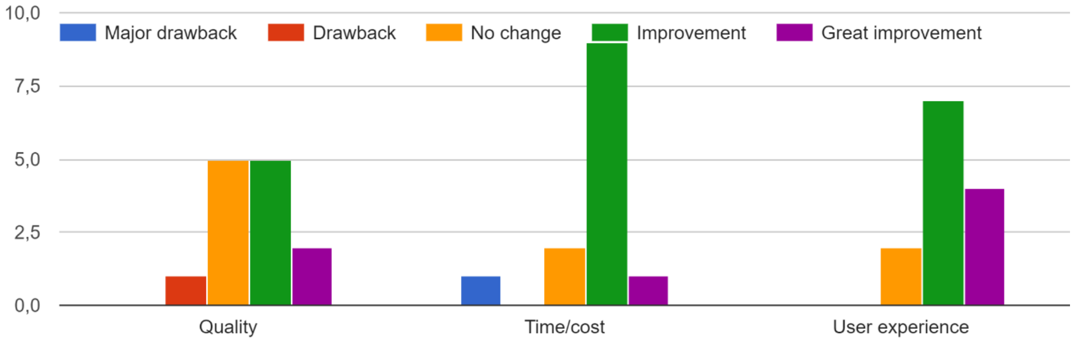
EQUIPMENT VERIFICATION, checking which equipment is needed for the manufacturing process



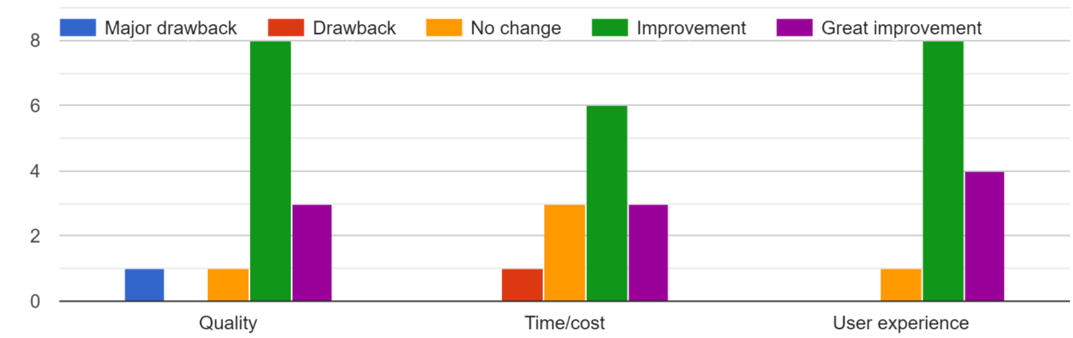
STUDY PROCESSES, Checking if the processes are possible to preform at the factory



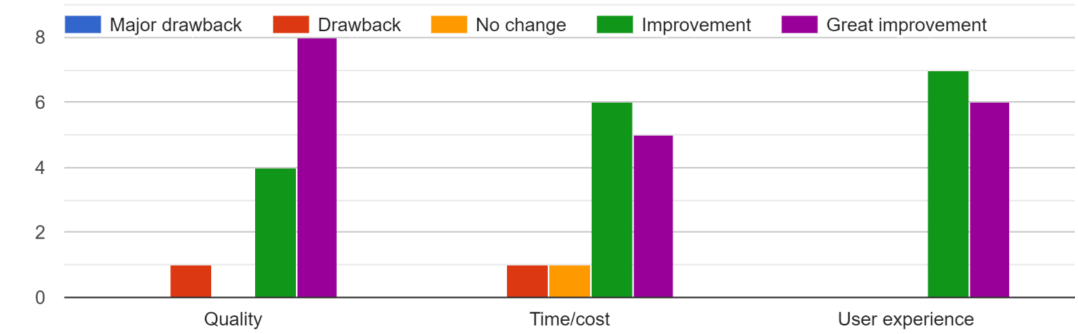
ASSEMBLY GEOMETRY, ensure that all parts can be assembled without clashes



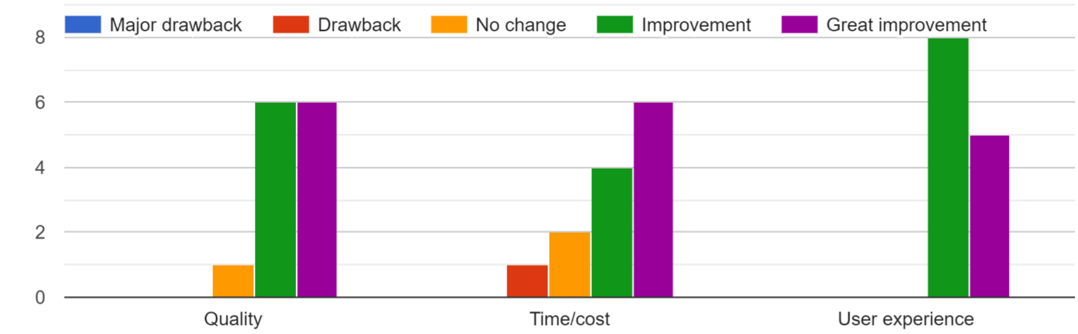
SAFETY OF OPERATOR, evaluate the safety of the operator during the manufacturing processes



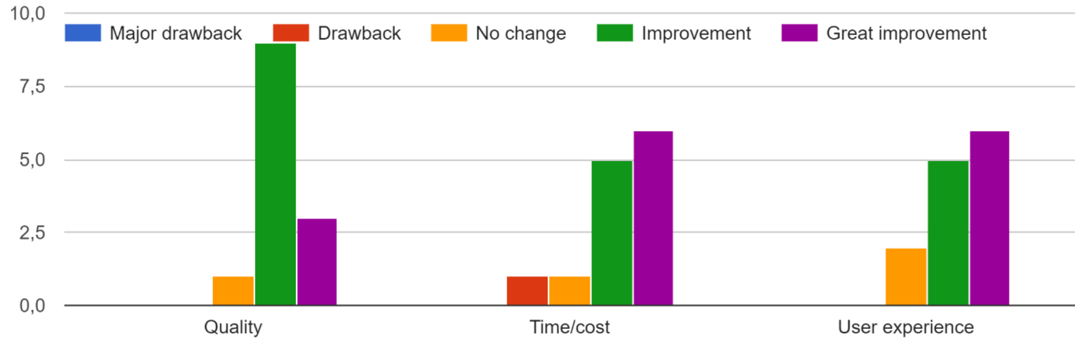
MEETINGS, when sharing information with multiple people in a room



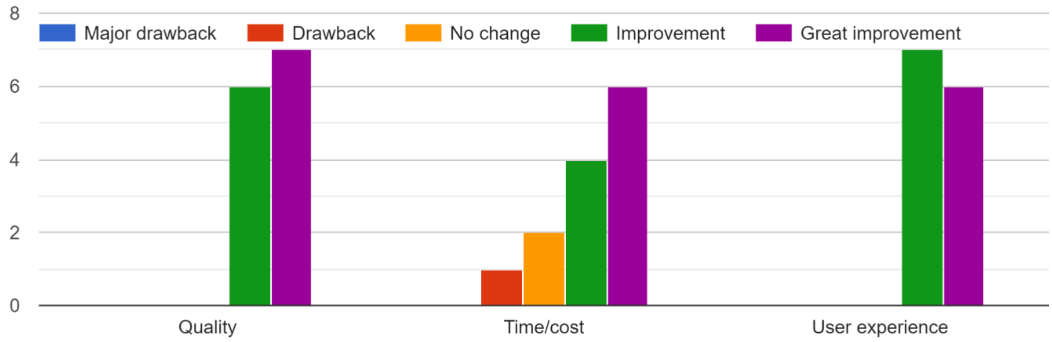
COLLABORATIONS, when working together and solving problems (both within and in-between departments)



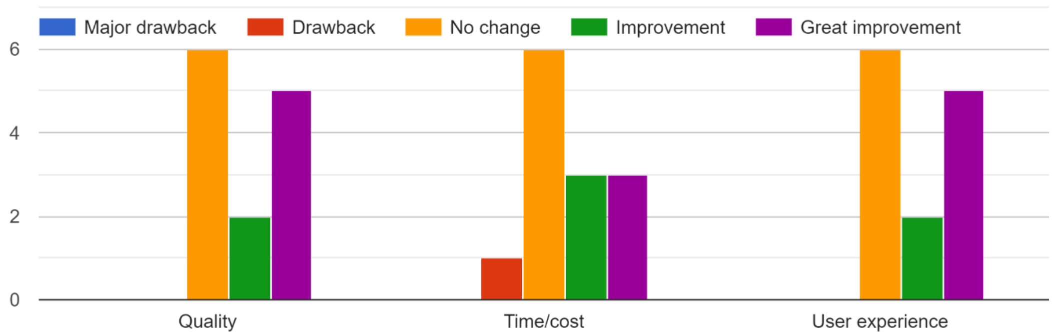
DISCUSSIONS, when discussing changes to concepts or product specifications



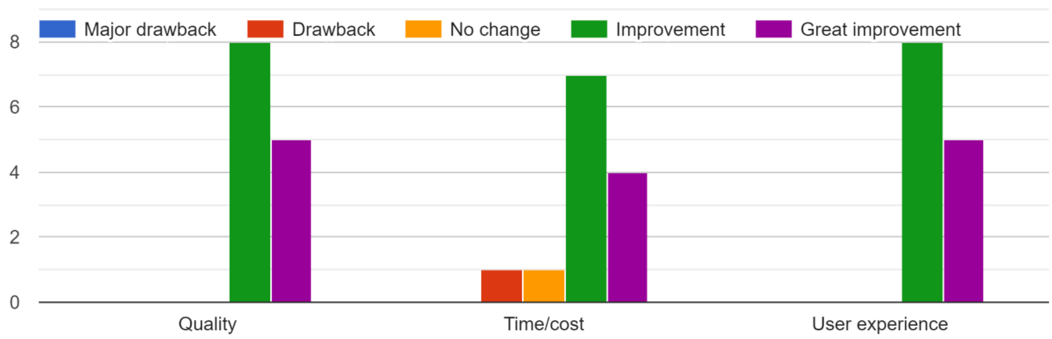
CLAIM SUPPORT, motivate a change and increase validity of statements



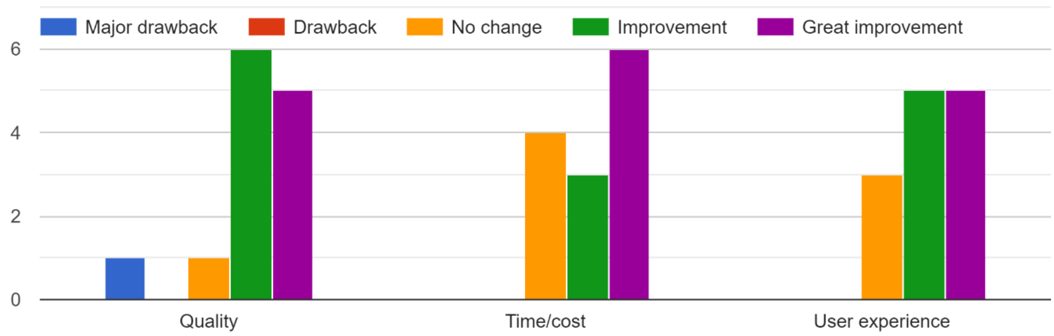
STATUS REPORTING, documenting changes made (tools today are DPA5, PCR, Excel)



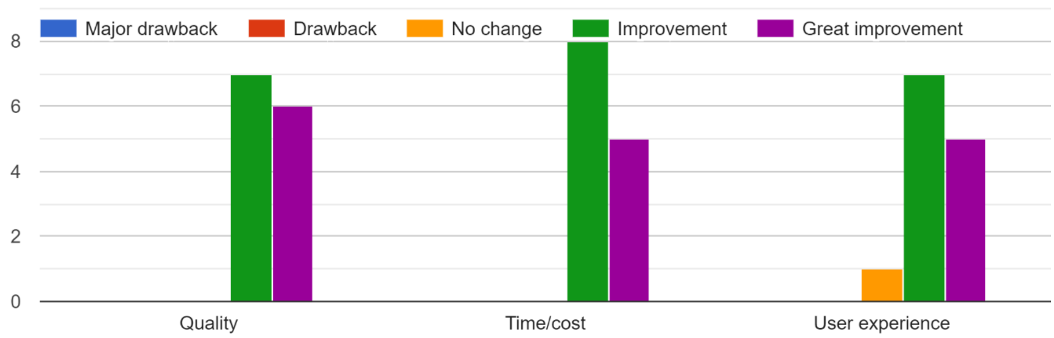
WORK INSTRUCTIONS, explanations to an operator on how to preform the process



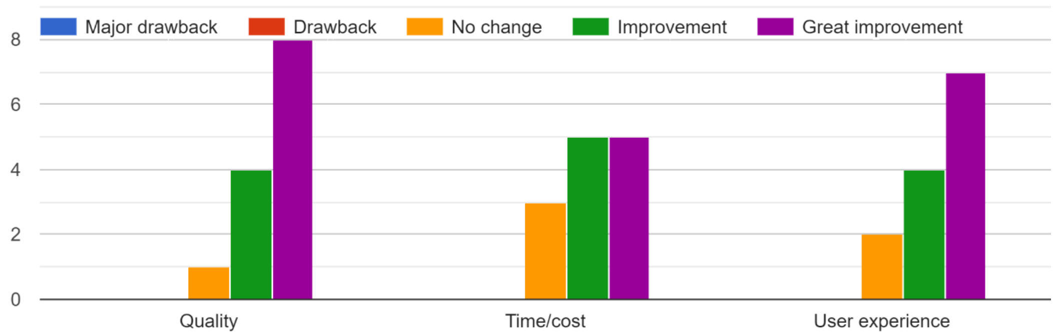
PERCEIVED QUALITY, considering and evaluating the customers visualization of the final product



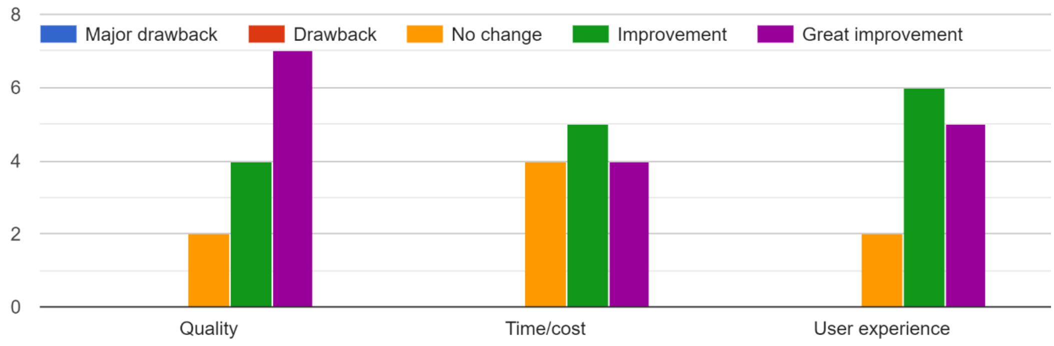
CONCEPT VERIFICATION, checking if the concept is possible to manufacture or what changes are necessary to do



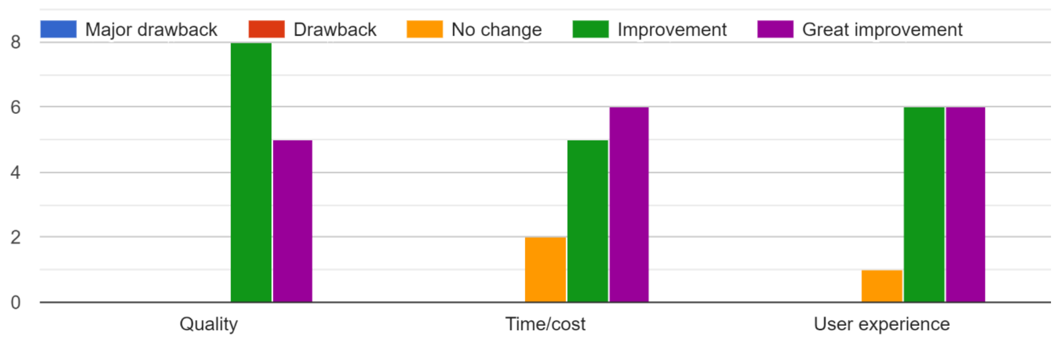
EXPERIENCE FACTORY LAYOUT



EXPERIENCE LINE LAYOUT



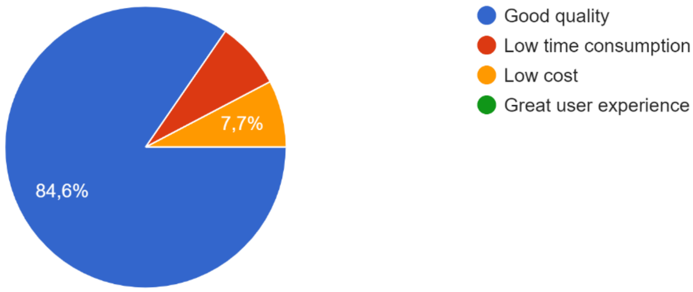
EXPERIENCE CELL LAYOUT



C.4 Evaluating importance of different factors

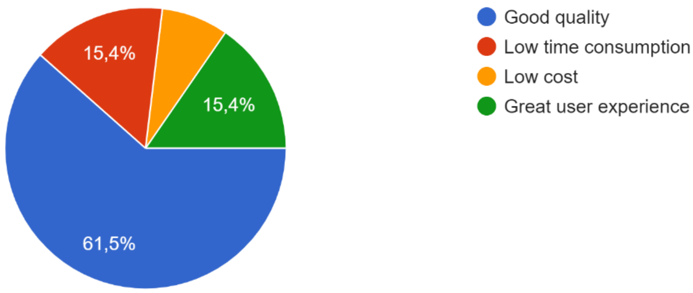
When you are analyzing a problem, which factor is most important?

13 svar



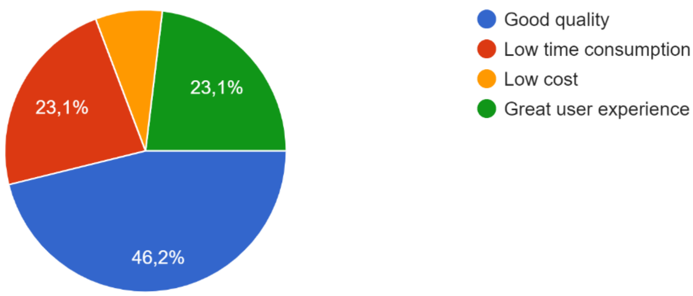
When you need to communicate a solution to a problem, which factor is most important?

13 svar



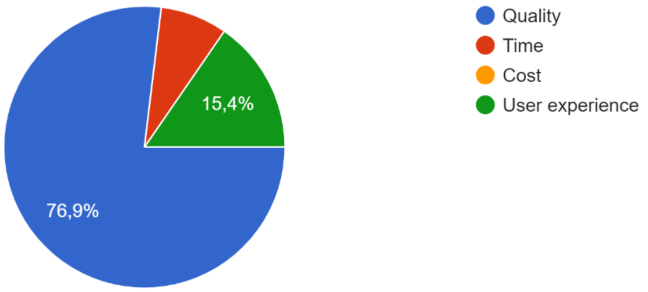
When you need to visualize a problem, which factor is most important?

13 svar



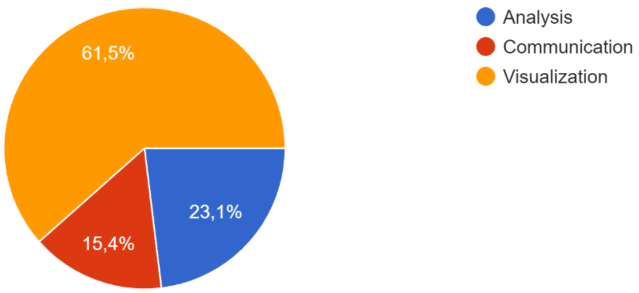
In general, which factor is most important?

13 svar



In which areas of activities do you think VR can be most beneficial for the improvement of current work-practice?

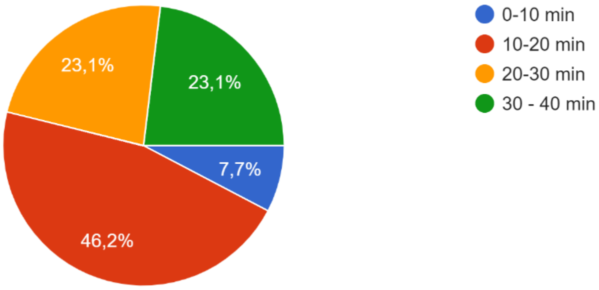
13 svar



C.5 Use of VR in work processes

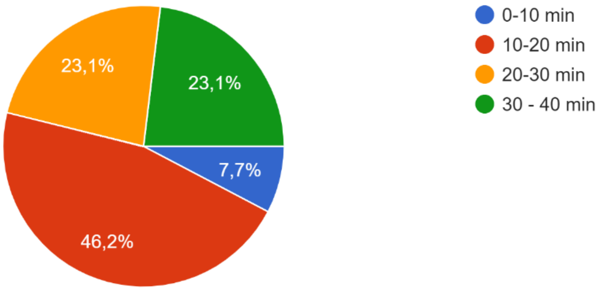
Before utilizing VR, how much time do you feel is acceptable when doing preparation work?

13 svar



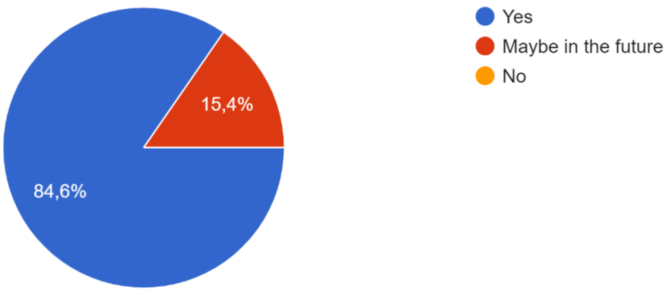
Before utilizing VR, how much time do you feel is acceptable when doing preparation work?

13 svar



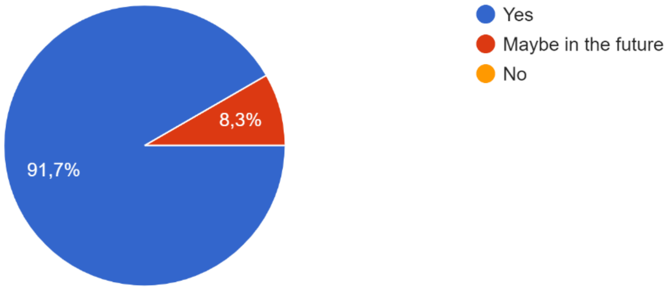
Is VR something you feel that you can utilize in your work?

13 svar



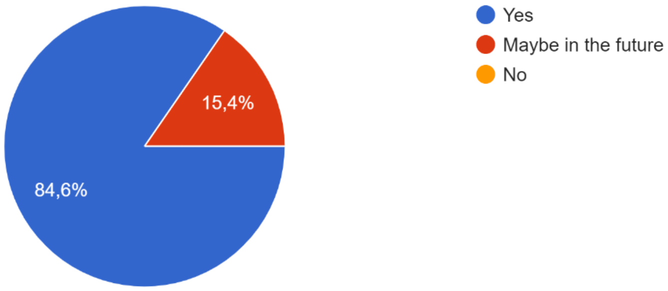
Do you believe VR can be a facilitating tool when you analyze different problems?

12 svar



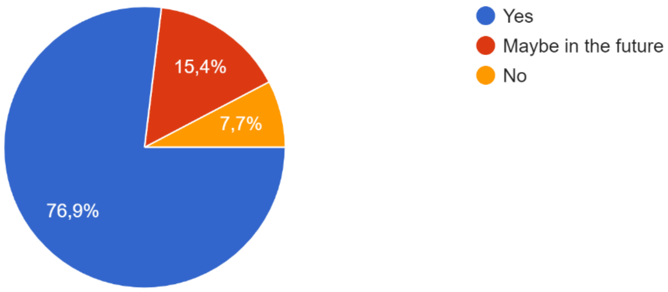
Do you believe VR can be a tool facilitating your communication when discussing a problem with a colleague or in a meeting?

13 svar

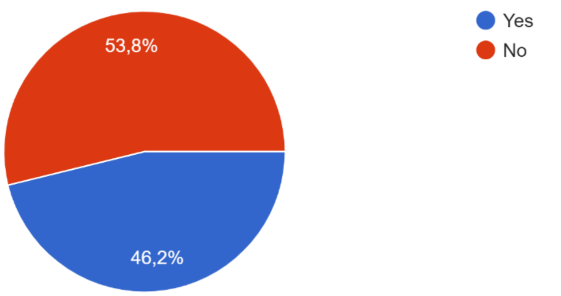


Do you believe VR can be a tool facilitating visualization when performing your work tasks?

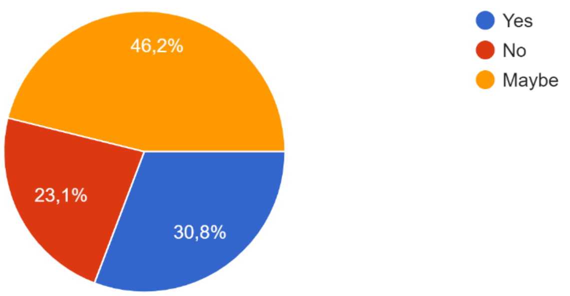
13 svar



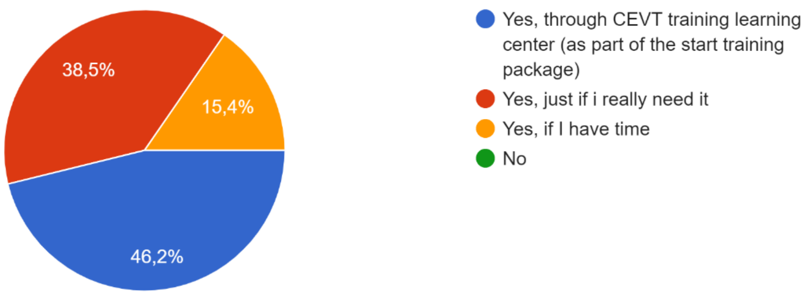
Do you know how to utilize CEVTs current VR capabilities for your work?
13 svar

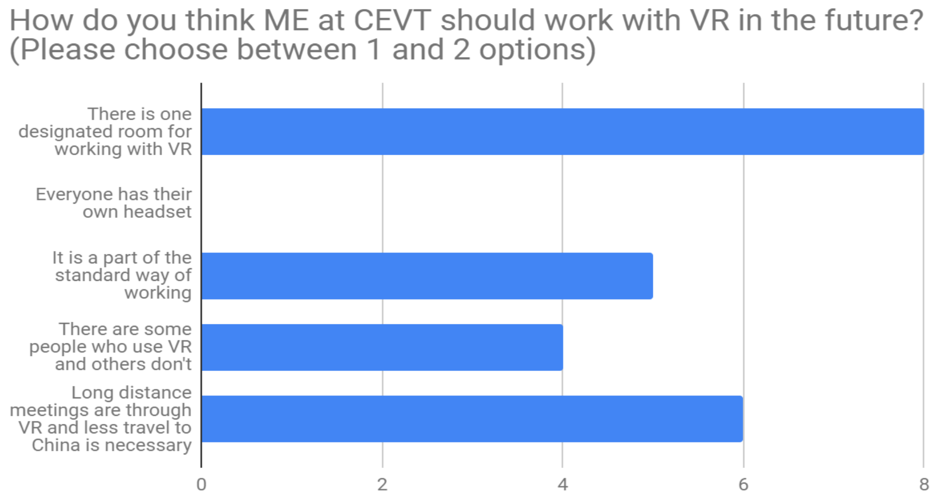


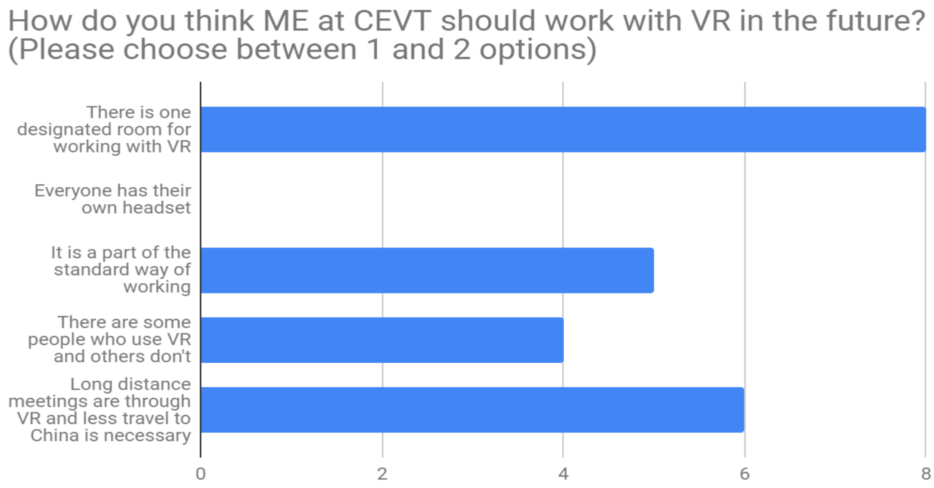
Do you have a clear picture of how VR can suit your work?
13 svar

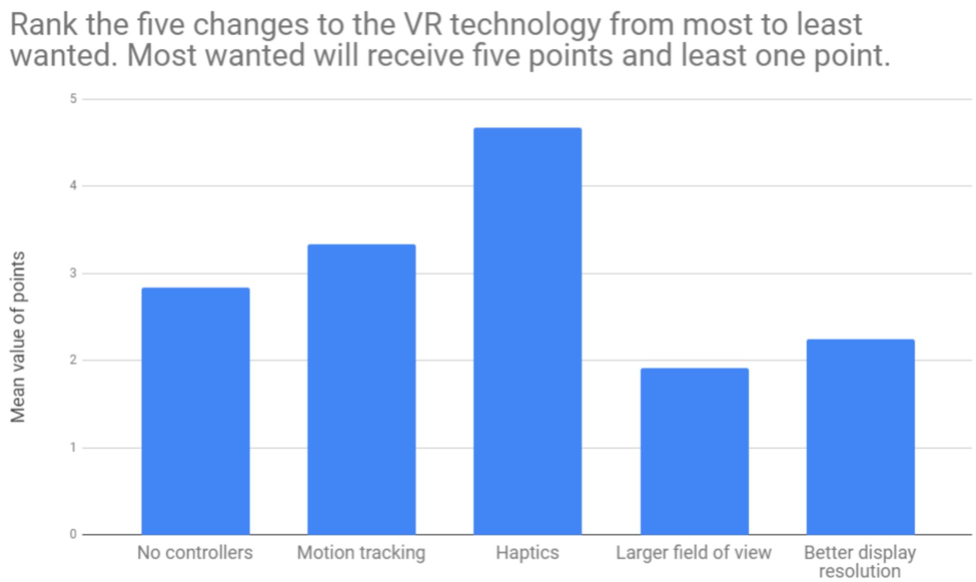


Would you like to learn more about VR?
13 svar




How do you think ME at CEVT should work with VR in the future? (Please choose between 1 and 2 options)
There is one designated room for working with VR
Everyone has their own headset
It is a part of the standard way of working
There are some people who use VR and others don't
Long distance meetings are through VR and less travel to China is necessary
0
2
4
6
8


How do you think ME at CEVT should work with VR in the future? (Please choose between 1 and 2 options)
There is one designated room for working with VR
Everyone has their own headset
It is a part of the standard way of working
There are some people who use VR and others don't
Long distance meetings are through VR and less travel to China is necessary
0
2
4
6
8


Rank the five changes to the VR technology from most to least wanted. Most wanted will receive five points and least one point.
Mean value of points
5
4
3
2
1
0
No controllers
Motion tracking
Haptics
Larger field of view
Better display resolution

D

Guidelines and recommendations to case company

D.1 Summarization of the result

Immersive technologies should be used in the work processes at ME CEVT. In general, it is important to understand that VR should NOT be used as a substitute to current work processes but as an additional tool to create better or quicker results. The major reason for ME to use VR is to have a better tool for analysis, communication and visualization, it is in these three areas the greatest potential lie.

The work processes, where the greatest potential have been found, are within collaborative meetings and ergonomics. Using VR for collaborative meetings adds an additional tool to visualize different parts of the product. Compared to current work processes, this can facilitate when trying to explain and discuss different problems.

Within ergonomics it is possible to experience the operators work position or to evaluate if it is a reachable position. The current VR setup can be a simple tool for most departments to use for a fast and easy evaluation instead of making a major ergonomic evaluation. The level of work within ergonomics varies a lot between the different departments and therefore the requirements on the VR equipment also varies. In the future for deeper ergonomic evaluations, where for example path planning, statistical analysis of the movements and greater anthropometric values can be analyzed, other additional peripherals would be necessary and further development of IPS as well.

Examples of the tests and tasks we suggest VR should be used for within ergonomics are:

- **Path planning operators' tasks**: In the VR environment decide a path which the operator should follow and then receive ergonomic statistics for the whole manikin family if they were to follow the same path. Currently the path needs to be created manually at the desktop setup which takes a long time. This needs to be developed in collaboration with IPS.

- **Experience operators work situation**: In the VR environment it is possible to experience the operators work position, which is necessary to evaluate when making recommendations of a weld process, a manual paint process or an assembly. Currently when making decisions for example what weld gun to use, this is based on previously acquired knowledge. With VR the situation can be visualized in scale 1:1 and the operators work situation can be experienced instead of estimated.

- **Ensure safety of operator**: Sometimes harmful situations can be discovered in the actual production such as sharp edges that might damage hands when in contact because of a narrow space. These might be hard to visualize and perceive the surrounding space on a desktop and in VR it might be possible to discover these tight areas before they go into production.

Both communication and ergonomics are possible to apply in current work processes today since the technology is ready for it and both processes also have potential to develop into a tool for deeper analysis if other hardware or further developed software is used in the future.

The level of knowledge of VR in the ME department is in general quite low. However, once the VR environment is set up most people tend to understand quickly how to use the tool. There are a couple of individuals with more knowledge of the technology which is a great strength for ME department. To lift the overall level of knowledge, on how to use VR, a course or more information should be distributed to everyone. This could be done by more collaborations with the people with more knowledge or having training sessions. If people have more knowledge on how the VR tools work, they will also see the possibilities for how it can be used to facilitate in their own work processes. It is important to make the people feel involved so that they in the future will pick up the tool themselves because they need it and not because they are forced to use it.

D.2 Potential benefits if implementing VR

With the use of VR there are several cases both within the company and other instances where VR have been shown to have benefits within time, cost, quality and user experience.

D.2.1 Time/cost

Within the time and cost area the benefits of using VR is to lower the time consumption of tasks and in that way reduce cost of activities. One example of this is when using VR within a collaborative engineering meeting it was estimated that this saved between 4-6 additional meetings. VR have been shown to reduce the knowledge gap between people from different disciplines. The object in question can be seen from a common viewpoint and therefore it will be easier to discuss and understand. 4-6 engineering meetings with a duration of an hour and with 5-10 engineers will mean a time save of 20-60 engineering hours for each time.

Assembly steps can also be tested in a virtual environment which creates the possibility to use an additional tool instead of only basing a decision on experience or making a full simulation. Testing the assembly will likely be faster in VR than performing full simulations for each assembly and give better judgement than only basing the decision on experience. If problems are found when testing the assembly in VR it may need further research. This will save time from doing multiple long simulations. Another example is that it can save time by not having to do a physical build. In some cases, there is no need for a physical build when the concept can be verified in a virtual environment instead. It may be enough to convince the affected people that the concept will function properly instead of needing to build it physically.

Another area connected to this is when using VR in an early phase of a concept. The earlier problems are detected the more time and money will be saved. Finally, VR can potentially decrease the number of travels to China since some tasks will be possible to do through VR instead of being in the same physical location.

D.2.2 Quality

Within the quality area the benefits of using VR is connected to minimizing errors and miscommunication. With VR it is possible for a clearer information exchange during for example meetings. When minimizing the miscommunication, it will reduce errors in decisions or discussions. The quality will also be improved when using VR in an early phase to find errors. To ensure that the quality will not be decreased it important to make sure that the virtual environments are correctly built to represent reality and that they include the necessary functions, such as collision detection and visual feedback, to work properly.

D.2.3 User experience

Within the user experience area, the benefits of using VR is an increased sense of immersion but also gives another type of interface compared to working with a screen. It gives the person the possibility to visualize product in scale 1:1 and interact with the 3D virtual objects. For the user experience to be good it essential that the equipment being used works. The computer that the VR setup is connected to should be powerful enough to handle the VR environments without problems so that the user experience is not compromised.

D.3 Time plan

Here is a recommendation of the steps to take with the VR initiative based on the findings we have made during our thesis.

- **Step 1**: Focus on the current VR technology you have now. This is a basic setup that is easy to learn and get used to which allows for more people to easily be able to start using it. This will also allow the people with more knowledge to become experts. You should also still focus on the software that you are using, i.e. IPS and Process Simulate, since you already have experience with it. For the departments that doesn't use these programs it is still recommended to use them since there are support and help to be found within the ME department. The people with more knowledge should introduce others to VR. Easier visualization tasks can be introduced and taught in IPS first since this do not require any advanced preparations or deeper knowledge of the software. Game engines should not be focused on since these will require further knowledge and is not needed for the activities.

- **Step 2**: Start implementing VR in the activities that have been found to be beneficial and that are ready to implement, i.e. the activities that are marked green in the thesis report. Implementation of VR for the activities should start at a small scale or level and increase over time.

- **Step 3**: A way to educate everyone on how to use VR should be created. The purpose of this education should be to teach how to use VR, what needs to be prepared in the software, how to set up the VR equipment in the VR room, how to interact in the VR environment. This would allow for people to create more advanced VR environments. From the survey it could be seen that a short preparation and setup time is wanted. More knowledge and experience about the technology would reduce the time needed to utilize the VR equipment.

- **Step 4**: Make the available VR resources more accessible. Make it so that the room can be booked online and that everyone can access the headset and controllers without having to ask for a key.

- **Step 5**: Investigate using more advanced equipment. Haptics, multiple users in the same environment and motion tracking is example of technologies that should be implemented in the future. Haptics should have the highest prioritization since it was voted as the function that would improve the VR experience most and give better quality and user experience. Assembly geometry assurance would especially benefit from the implementation of haptics. Multiple users would increase the possibilities for collaborative meetings and improve the communication even further. Motion tracking would be beneficial when working with ergonomics as data from the motion tracking could be gathered and transferred to ergonomic manikins. In collaborative meetings a virtual body could also be added by motion tracking.

- **Step 6**: Continue to follow the development of VR technology and additional peripherals. VR moves quickly and it's important to stay updated to make the most out of the technology.

D.4 Virtual Reality organization

If VR is going to become a resource that is being used more it should be given an organization to support it. One vision for this is that each department, e.g. ME and VI, have their own knowledge about how to use VR at their departments and have good knowledge on how VR can be used with the common software used at the department. There should also be a central VR department that can support the other departments with special cases that requires more advanced knowledge in VR and the use of game engines. This department will keep updated with the advancements within VR technology and inform the other departments about what is available. Another function this department can provide is education. The education can include information about the VR hardware, general software and requirements to use VR.

D.5 Virtual Reality setup

For the future setup of VR at ME a suggestion is to have one room that is designated to use VR in. This room should be designed with some additional requirements connected to the use of VR, meaning that it should have a large area for the user/s to move around on without having to worry about walking into anything. One solution would be to place a different carpet on the floor within the VR zone so that the user can feel when they step out of the zone while being immersed in the VR environment. The wires that are connected to the headset could be mounted in the ceiling so that they do not become an obstacle for the user. Wireless HMDs should also be considered as an option. As much as possible of the setup should be permanent so that the time needed to set everything up will be reduced. A good network connection is important to ensure that VR meetings can be held with people in different locations. Large monitors should be installed so that others can observe what the user is seeing. There should also be a meeting/conference table, outside the VR zone, so that it is possible to have collaborative meetings there. When the use of VR increases and if it is specified to be a part of a standard way of working at ME one room will not be enough. One solution to this could be to invest in standalone VR HMD when they have become good enough or create more VR rooms with not as many features as the main VR room. Standalone HMD can also help with the implementation since they will be easier to setup and bring to meetings instead of needing to have meetings in the VR room. It is not believed that everyone will have their own HMD. However, if the usage time of each HMD is increased it might be motivated to invest in additional HMDs.

D.6 Recommendation for continued research work (AE projects)

To continue the research within this field a suggested similar area to investigate is Augmented reality (AR). As stated in the report AR have not come as far as VR in its development but it should still be investigated since it is a technology that is evolving and being improved quickly. Example of this is the HoloLens that is being developed by Microsoft which got a new updated release, HoloLens 2, in the spring of 2019. Compared to VR, AR provides the possibility to combine physical objects with virtual objects which can allow for other types of interaction. Work task instructions for operators through AR is one area that could be explored for the ME department.