Virtual Reality and Augmented Reality

A Survey from Scania’s Perspective

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2019

Master of Science Thesis TPRMM 2019
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Abstract

Virtual reality and augmented reality are technological fields that have developed and expanded at a great pace the last few years. A virtual reality is a digitally created environment where computer-generated elements are displayed to a user via different interfaces for the respective senses. Video is used for displaying images, creating a realistic environment, while audio is played to stimulate hearing and other sorts of feedback is used to stimulate the sense of touch in particular.

Augmented reality is a sub-category of virtual reality where the user sees the real surroundings, but computer-generated imagery is displayed on top of objects in the environment. This type of technology brings a lot of new possibilities and potential use cases in all sorts of areas, ranging from personal entertainment, communication and education to medicine and heavy industry.

Scania is a global manufacturer of heavy trucks and buses, and provider of related services, based in Sweden. By studying Scania’s different departments and surveying the fields of virtual reality and augmented reality, the aim of this thesis is to identify situations and use cases where there is potential for Scania to implement virtual reality and augmented reality technology. This thesis also studies what obstacles implementation of these technologies bring.

This thesis does not conduct any new research in the topic, but presents a summary of the state-of-the-art technology and research of virtual reality and augmented reality. It also presents a thorough description of Scania’s departments, with focus on production and logistics, and research and development, along with an analysis of where virtual reality and augmented can be implemented. The greatest potential use for virtual reality is within research and development, where it provides new possibilities for communication and presenting products and parts in life-like situations in different Scania settings early in the development process. For augmented reality, the best potential is within production and logistics, with emphasis on the latter. Here it can provide new ways of working, with shorter times from picking to delivery and quality verification done by machine instead of manually. Lastly, this thesis discusses which areas are best suited for virtual reality and augmented reality, what obstacles exist and how to handle them, along with presenting a road map with a recommendation for how Scania should proceed.

Among other things, this road map suggests to standardize what equipment and software to use, to build and maintain an internal network for employees working with these technologies, and to build automated processes for providing 3D models of Scania’s parts and products in formats that are suitable for use in virtual reality and augmented reality.
Sammanfattning


Scania är en global tillverkare av tunga lastbilar och bussar med tillhörande tjänster, baserad i Sverige. Genom att studera Scanias olika avdelningar och kartlägga teknikområdena virtual reality och augmented reality, är avsikten att identifiera situationer och användningsområden där det finns potential att implementera virtual reality och augmented reality på Scania. Arbetet undersöker också vilka hinder som står i vägen för implementation av dessa två teknikområden.

Acknowledgements

I want to thank my amazing fiancée Sanna for always providing support, being understanding and patient, and bringing the joy and positive spirit I much needed to come to this point in life. And I am also thankful for my daughter Elsa, who make me happy whenever I get home and make me know I have something else waiting for me, and thereby giving me the extra push I needed to finish this project.

Anna Holm and Lars Wejde, my Scania supervisors, have been a great support and encouragement during this project. Their open minds and loose reins allowed me freedom to form this project how I wanted to, while it also inspired me to keep working. Thank you for believing in me and my work from the start.

I want to thank Mimmi Rigler, my manager, for her great leadership, supporting me and giving me the freedom to carry out this project at my own pace, while also allowing me to travel and purchase equipment for testing, giving the project an extra edge.

Additionally, I also want to thank YMSC as a whole, my new group at Scania, for welcoming me into the group, and being inquisitive and showing interest in my work along the way.

Lastly, I want to thank my supervisor and examiner from KTH, Per Johansson and Lasse Wingård, for providing academic feedback on my work and showing support in both this project and during my master’s degree education.
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<td>AR</td>
<td>Augmented Reality</td>
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<td>AV</td>
<td>Augmented Virtuality</td>
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<td>BOM</td>
<td>Bill of Material</td>
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<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
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<td>CAE</td>
<td>Computer Aided Engineering</td>
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<td>DR</td>
<td>Diminished Reality</td>
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<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<td>FLP</td>
<td>Factory Layout Planning</td>
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<tr>
<td>HMD</td>
<td>Head Mounted Display/Device</td>
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<td>MR</td>
<td>Mixed Reality</td>
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<td>P&amp;L</td>
<td>Production and Logistics</td>
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<td>PDM</td>
<td>Product Data Management</td>
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1 Introduction

1.1 Background

The term “virtual reality” describes a world not existing physically, but only in a digitally created environment. It is worth noting that while any digitally created environment could be considered virtual reality by this definition above, the concept implies that the user is more surrounded by the virtual environment than just looking at it on a normal monitor. (Mihelj, et al., 2014)

Virtual reality as a concept was coined in the 1930’s but got its first real use in the 1950’s, when the first virtual reality machine was developed. Since then, development in the field has progressed and the technology has advanced past several important milestones which has formed how it looks today. (Mihelj, et al., 2014)

In the 1990’s, there were several consumer products on the market, but none of them worked satisfactorily. The visuals were in low resolution and slow, which caused nausea for the user and the realistic experience was not impressive enough to immerse the user. This led to the development slowing down. (Mihelj, et al., 2014)

It is just in recent years that technology development has advanced so much that virtual reality has reached a point where it can be considered mature and fit for use. The possibilities the technology provides and the areas in which to utilise them are plenty. For most people, however, augmented reality and virtual reality are most likely related to video games and leisure applications. But within many industries and lines of businesses, these technologies are the latest in line of development, paving the way for a lot of new opportunities. Being a manufacturing company in the world of today is a demanding task. Increased requirements and demands regarding quality, customization and shorter lead times puts pressure on companies to perform. One way of doing this is by being modern and continuously using new technology, such as virtual and augmented reality.

Scania CV AB (henceforth referred to as “Scania”) manufactures heavy trucks, buses and engines for industrial and marine applications, and services for and around the other products (Scania AB, 2018). The car manufacturing industry have been using virtual reality for several years, while the commercial vehicle industry has not come as far.

Within Scania, one department is responsible for management of the internal product data and product description structures and systems. To be able to deliver the proper data and information to the rest of the organization, a mapping of the company’s needs and interests in AR and VR is needed. In addition to the mapping, there is need for a plan describing how AR and VR is to be implemented within Scania, and what requirements need to be fulfilled for the plan to be completed.

1.2 Objectives

The main objective for this thesis is to survey Scania’s ongoing initiatives to implement AR and VR into its operations and supplement these with additional observations and suggestions for suitable areas of implementation.

The background and the objectives break down into five research questions that will be the basis for this thesis:
Where within Scania is there a need and/or use for VR and AR, especially focusing on the production area?

• What VR and AR solutions exist for applications within Scania?

• What are the gains with using VR and AR within Scania, and how do they contrast the costs of implementation and regular use?

• What implementations should be made within a year, five years and ten years?

• What gaps between current initiatives and Scania’s product description data exist?

1.3 Goal/Purpose

The goals of the project can be summarised into four distinct points.

• Investigate the need for VR and AR within Scania.

• Deciding what areas to focus on.

• Outline what activities are needed to partake in order to succeed.

1.4 Limitations

The field of virtual reality is large and has a broad spectrum of uses. For instance, augmented reality in the form of heads-up displays are getting more common in cars and trucks, enhancing the driving experience and increasing security by allowing the driver to focus more on the road. However, such use cases will not be a part of this thesis. Use cases aimed for Scania’s customers will also not be discussed in this thesis. Instead, this thesis is aimed to find possible use cases for employees at Scania and investigate how their work environment can be improved by using virtual reality and/or augmented reality in their daily work. The whole process within Scania, from attracting customers and receiving an order to delivery of the product to the customer will be part of the scope of the thesis.

As the project aims to provide a broad view of the field of virtual reality, the literatures study will reflect upon this by being broad and not deep. This means that no new research will be carried out during this project. Existing research and technology will not be discussed in depth in favour of a wider scope where general principles are described instead.

The analysis and implementation will be focused primarily on two areas, where one is production and the other is research and development. There are several reasons why these areas have been selected. As this thesis is part of a management, production and industrial engineering programme, it has to have a connection to production. Another reason for choosing production is because a lot of Scania’s business is formed around production and manufacturing, and it being efficient, productive and delivering good quality. Thus, there is a lot of potential for using modern technology such as augmented reality to enhance these key values. The research and development area has been selected as it is also a big part of Scania’s business.

This thesis project is assigned by a group at Scania called YMSC, responsible for methods and processes related to Scania’s CAD and vPDM systems platforms. See Appendix A for organizational chart. YMSC’s have previously focused solely on its customers in research and development, and its deliverables are mainly focused on research and development users. However, recently there has been an increased focus to include all customers using the CAD and vPDM systems platforms. All employees and users who access some information in the product description are customers, however, and this is likely to increase as the usage of virtual and augmented reality gets more and more common within Scania.
As Scania is a large company with a lot of different branches, there is likely a lot of different users and use cases that can gain from virtual and augmented reality. But due to the time constraints of this project it is not possible to investigate all of these as thoroughly as the branches of production or research and development. It is important, however, to get as broad a picture as possible of Scania’s users and potential use cases.
2 Methodology

This section describes the methodology applied to conduct the work for the project according to given initial conditions, goals and limitations. The section is structured to follow the chronological progression of the project, describing the main stages and phases as they were handled.

2.1 Background research

The research for the project will be conducted as two separate parts, running in parallel. One part will be an investigative study and the other part will be a series of interviews.

The investigative study itself will have three different areas with different focuses and purposes. A literature study will be conducted to provide a solid background into the subject of virtual reality and its related topics and subtopics. Adding to the literature study will be a state-of-the-art research within in the field, aimed at the automotive and manufacturing industries. The state-of-the-art study will serve as a reference point for determining how far Scania has come in using virtual reality technology and what lies ahead. This includes what technology is available now and what is going to mature in the coming years, thus being an input to the roadmap and implementation plan that this project will produce. Lastly, competitors and actors in similar industries will be reviewed in a comparative study. The comparative study is a complement to the state-of-the-art study and will thus add insights into what Scania could learn from other truck manufacturers and similar companies.

In addition to the investigative study, a number of interviews will be conducted. These interviews will be held with knowledgeable personnel at KTH, where the goal is to collect additional research related information, and other interviews with Scania employees.

The interviews with Scania employees serve two purposes. One purpose is to find out what areas within Scania that are currently working with virtual reality or augmented reality. This is important, as it is then possible to share knowledge among the users and the rest of the organisation. Another aspect of this mapping is to find out what needs and requirements the users have to improve their work. The second purpose is promoting the use of virtual reality and augmented reality to areas that are not yet using it.

The selection of interviewees will be done by evaluating personal contacts at KTH and within Scania and determine if they possess needed insights or knowledge, or they themselves have valuable contacts.

All interviews will be conducted verbally in person or by telephone. Each interview will have a number of standard questions, such as what the person is working with, what their knowledge of augmented reality and virtual reality is, and what their department or group is doing in the world of augmented reality and virtual reality. This approach of fewer, more in-depth interviews is called a qualitative study, in contrast to a quantitative study where a series of many shallow interviews would be conducted. (Trost, 2010)

Additionally, each interviewee will also get a number of questions specific for them that allows follow-up questions and open up to a discussion. Such interviews, called semi-structured interviews, are useful when the expected outcome is not foreseen, but determined by the conversation. (Björklund & Paulsson, 2003)
2.2 Analysis
The background research will be analysed from the perspective of Scania wanting to improve and increase their usage in the field of virtual reality. Thus, the analysis will serve to determine what technology and research that is of the most use for Scania. Both such technology that is ready for implementation today, as well as such technology that will mature within the time frame of the resulting implementation plan will be considered.

A proposal of situations and areas within Scania that show greatest promise for where AR and VR should first be used and implemented will be formulated, using the state-of-the-art analysis and the study of Scania. This evaluation for this proposal will be performed together with my supervisors at Scania to confirm that the results of the analysis is in somewhat align with the general roadmap for development within this area at Scania.

2.3 Development
Scania wants a plan for how to continue working with augmented reality and virtual reality. This report aims to provide this plan and suggest actions, based on the analysis, within the selected focus areas. As there most likely will be more possible implementations than there are uses at Scania, only actions for applicable uses will be suggested. The implementation plan will be general and is aimed to suit several departments and units at Scania.

How implementation could look at an assembly unit will be presented by composing a more detailed plan. The plan will be formulated for use in the axle assembly in Södertälje.

2.4 Evaluation and future activities
When the main work of the project is concluded, a self-critical review of the whole process will be done. It serves to evaluate how well the results of the project aligns with the defined scope, what has been added and what has been left out. Furthermore, it is even more important to determine what should have been included or what has not been finished. This is the baseline for what future activities are to be performed.

This project aims to lay a foundation for Scania’s work in the field of AR and VR from the perspective of what Scania’s product description has to provide. As such, a roadmap describing what activities need to be performed and when they need to be carried out in order to achieve set goals will be presented. The last part of this report will suggest what to do to carry on the work that this project has paved the way for.
3 Terminology and background descriptions

3.1 Reality and virtuality

This segment aims to explain the basic terms in the field of virtual and augmented reality. The following chapters will describe the background of the field and explain relevant terms and how they are connected to the field and each other.

3.1.1 Reality-virtuality continuum

The reality-virtuality continuum is a continuous scale that was introduced in 1994 by Paul Milgram (Milgram, et al., 1995). It spans from a completely real environment to a completely virtual environment – a virtual reality (VR). The span between the two extremities is a range called “mixed reality” (MR), while technology enabling immersion into mixed realities is commonly referred to as “immersive technology”. (Mihelj, et al., 2014)

![Reality-virtuality continuum as described by Milgram](image)

3.1.2 Virtual reality (VR)

A virtual reality is a computer-generated simulation that aims to give the user realistic experience. The realism comes from immersing the user into the simulation by trying to excluding them from the surrounding real world. In order for this to be achieved, the simulation has to stimulate the user’s senses to such an extent that the user forgets the real world and is completely focused on the simulated reality. (Mihelj, et al., 2014)

Virtual reality is a term describing a computer simulated environment in which the user is placed in such a way that they feel immersed by it. This requires the simulation to stimulate the user’s senses in such a way that the user focuses on the simulation instead of their surroundings, making the experience feel realistic. The sensory stimulation is primarily comprised of visually presented information, while auditory and haptic stimulations are also common. There also exist systems that can stimulate other parts of the nervous system, such as the somatosensory system and the olfactory system. (Mihelj, et al., 2014) The somatosensory system responds to changes at the surface or inside the body, such as temperature, but it is also sometimes accredited to be the sense of touch in general. The olfactory system is responsible for the perception of smells. (Schmidt & Thews, 1983) Virtual reality systems that excite these senses have fewer uses and are uncommon. (Mihelj, et al., 2014)

3.1.3 Augmented reality (AR)

An augmentation is an amplification of a property, sense or signal of some kind. In the context of augmented reality, the perceived world is amplified with computer-generated information. A user in an augmented reality sees the real world as it is, but with additional data put into it. This is commonly done by overlaying the user’s vision and presenting select pieces of information that are of importance to the consuming user. The presentation of information is usually done in real-time. Augmented reality does not necessarily have to refer only to amplification of visual data, it could also potentially amplify hearing, touch, smell or taste too. (Furth, 2011)
There are a few ways to present the user with more information. Two common methods are either by head mounted display, or through a hand-held device, such as a tablet computer or a mobile phone. Both of these options are worn or held by the user during usage. A third option exist which uses video-projectors, holograms or similar to display graphical information onto real physical objects. These are stationary in the room, removing most of the technology from the user. One benefit is that this enables collaboration between many users in the same room. (Furth, 2011)

3.1.4 Mixed reality (MR)
In a mixed reality, there are always parts of both real and virtual elements. The mix ratio between the two environments in turn have different names depending on which environment is featured in which. In a mix where the real environment is the foundation, and the virtual elements augment the real, the combination is called “augmented reality” (AR). Conversely, a mix where the real elements augment the virtual environment, it is called an “augmented virtuality” (AV). (Milgram, et al., 1995)

3.1.5 Augmented virtuality (AV)
In contrast to augmented reality, an augmented virtuality is an environment which is largely virtual, and real elements augment it. An example is a virtual world into which a real person’s physical appearance is added. (Mihelj, et al., 2014)

3.1.6 Diminished reality (DR)
A variant of augmented reality, where information is removed, replaced or made transparent, is called “diminished reality”. It follows the same principles as an augmented reality, but instead of adding more to the world, elements are concealed or visually hidden, thus diminishing the seen world. (Mori, et al., 2017)

3.1.7 Avatar
A representation of a user in a virtual world is called an avatar. As the avatar is a digitally created being, it does not have to obey to the same set of rules as a being would have in the real world. This creates the possibility to have any type of avatar, as it is not limited by physics or chemistry. An avatar can be anything ranging from a virtual copy of the user’s physical appearance or something completely made up, be it biological, mechanical, robotic or something entirely different. However, creating an imaginative avatar brings problems with it. If the avatar is too divergent from the human body, a user can have trouble controlling the avatar, as the avatar’s movements does not naturally correspond to the user’s movements. This is especially true for VR applications, where the simulation often is based around a human, and the input methods are haptic controllers tracking the user’s movements when they are held in the user’s hands.

3.1.8 Virtual presence, telepresence and teleoperation
Virtual presence is a term for an abstract concept, specifically the feeling of being in an environment. This is done by convincing the user’s brain that the simulation is real with entirely psychological stimuli, or by also subjecting it to physical stimuli. The user has to get enough stimuli to detach themselves from the real world and be absorbed in the virtual environment instead. Then, the user is having a feeling of being in the digitally generated environment, thus having a virtual presence in it. (Mihelj, et al., 2014)

When a user, via virtual reality, is placed in real location that is geographically distanced from the user, it is called “telepresence”. In this setting, the user is able to interact with the surrounding
environment. If the user is not able to interact directly with the environment, but through some
device, it is instead called “teleoperation”. This method is often used to operate robots, such as
the Mars rover or surgery robots. (Mihelj, et al., 2014)

3.2 Senses
A person in any sort of situation use their senses to determine if the experience is pleasant and
enjoyable or not. As virtual reality aims to be realistic and convincing, it has to appeal to the user,
thus stimulate their senses.

It is traditionally said that humans have five distinct senses: sight, hearing, touch, taste and smell.
These are mainly connected to specific body parts and organs, namely the eyes, the ears, the nose,
the mouth and the skin respectively. But apart from these main senses, the human body is able to
detect other sorts of stimuli as well, meaning that the term “sense” incorporates more than the
traditional five senses. (Schmidt & Thews, 1983)

When a person is experiencing a situation or scenario, this experience increases in magnitude the
more senses are affected. An experience where the person is using all their senses makes a
stronger impression and has a greater impact than one where fewer senses are used (Mihelj, et al.,
2014). For a virtual reality simulation, it is generally desirable to stimulate more senses than sight.
In general, it is always the goal to make a virtual reality scenario realistic, and to do this the user
has to believe it is real. By manipulating more of the user’s senses with digitally created
stimulation signals, the user gets a greater experience, making it easier to believe, thus rendering
the simulation more realistic. (Mihelj, et al., 2014)

While the activation of many senses is important to enrich the experience, it is also important
that the signals from all senses give the person corresponding information. Signals that contradict
each other will confuse the person’s brain and may be sickness inducing. An example of this is if
the eyes perceive the person to be standing still, while the balance system perceive the person to
be moving. Such a discrepancy could cause motion sickness. (Schmidt & Thews, 1983)

While there are several theories as to why motion sickness occurs, the sensory conflict theory
described by Reason and Brand is the most widely accepted (Brooks, et al., 2010). In the area of
virtual reality, the disparity between what the user sees in the virtual world and feel in the real
world, is partly the cause of a phenomenon called “virtual reality induced symptoms and effects”
(VRISE) or “cybersickness” (Sharples, et al., 2008).

3.2.1 Sight
Virtual reality relies heavily on sight. Therefore, it is important to cover as much of a human’s
sight as possible. (Mihelj, et al., 2014) A human has a field of view of around 200 degrees
horizontally and 130 degrees vertically, when using both eyes. There is an overlap in the middle
where both eyes see the same thing. This overlapping area is almost circular with a diameter of
120 degrees, called the binocular field. (Traquair, 1946)

The front surface of the lens of human eye is capable of bending and becoming more or less
curved to enable the eye to focus on objects at different distances. This bending is called
accommodation. The range of accommodation is the range of distance of which the retina is able
to precisely focus on an object. As the lens of the eye becomes less flexible with age, it means
that the range of accommodation decreases. A young person may bring objects in sharp focus as
close as 7 cm from the retina, while adults over the age of 50 may very well have to hold the
object at arm’s length or up to a meter away for it to properly be in focus. (Schmidt & Thews, 1983)

3.2.2 Hearing
The human ear is the sensory organ responsible for hearing. It has three parts, the outer ear, middle ear and inner ear, and is part of the auditory system, in turn a part of the sensory system. Sound vibrations are captured by the outer ear and funnelled to the eardrum, located in the middle ear. Connected to the eardrum is the malleus, incus and stapes bones, commonly referred to as the “hammer”, “anvil” and “stirrup” respectively. These bones amplify the incoming sound vibrations before it is passed to the inner ear. The main part of the inner ear is the cochlea, which receives the sound waves and convert them into nerve impulses. (Schmidt & Thews, 1983)

While the outer ear captures sound vibrations, thus enables hearing, there are other ways of making a person hear. One of these methods is called “bone conduction”, where the sound is transmitted via the bones in the skull directly to the inner ear, rather than through the outer and middle ear. This method is used in several products, including headsets and headphones, hearing aids and communication devices. (Puria, et al., 2013)

Apart from hearing, the ears also have a central function in providing balance to a person. The inner ear comprises the organs for equilibrium, as well as hearing. There are two types of balance, static and dynamic. Static balance is where the person feels the effects of gravity, while dynamic balance is where the person feels the effects of acceleration. (Schmidt & Thews, 1983)

3.2.3 Touch
Touch is controlled by the somatosensory system, which in turn is part of the sensory nervous system. Its purpose is to register and respond to changes on the skin and inside the body. Touch is complex as it is affected by many different factors. Pressure, texture and surface roughness, temperature, and motion are all important to the sense of touch. Cutaneous receptors under the skin respond to the sensation and translate it into electrical signals. (Bensmaia & Manfredi, 2012)

3.2.4 Taste
Traditionally, it has been said that humans can distinguish four different tastes or qualities: sweet, sour, bitter and salty (Schmidt & Thews, 1983). However, a fifth quality has in recent years been recognised, namely “umami” (de Araujo, et al., 2003). Humans have taste cells on the surface of their tongues. Clusters of these cells together with support cells make up taste buds. The taste cells in most cases respond to more than one of the qualities, but are primarily stimulated by one of the qualities. The tongue has zones of specific sensitivity, where different stimuli are primarily acting on the taste cells, meaning that each of the five qualities are tasted on different parts of the tongue. (Schmidt & Thews, 1983)

3.2.5 Smell
The olfactory cells are located mainly in the nose, but also in the throat region. When breathing air, odour molecules are transported past the olfactory cells and its receptors. Humans can distinguish smells from several thousand of different substances, and each receptor responds to many of them. Unlike the classification of taste qualities, there is no clear way of dividing smells into different categories of qualities. Some classification exists and is generally named after the natural source that produce them. Two examples of this sort of classification are that the odour class “floral” smells like roses, while the odour class “putrid” smells like rotten eggs. (Schmidt & Thews, 1983)
3.3 Hardware technology and devices

This chapter will explain some of the most common variants of technology that is used to provide a virtual or augmented reality experience. Basic terms will be explained, and examples of common equipment will be shown. The equipment that is described is used in some way to stimulate one or more senses to provide realism to the user.

3.3.1 Display devices

3.3.1.1 Head-mounted display (HMD)

A head-mounted display is a piece of equipment displaying images or information to the user while they are wearing the device on their head. There are a number of typical model variants for an HMD. The most common variant in commercial products is the goggle-type HMD, which is used in both HTC Vive (HTC, 2018) and Oculus Rift (Oculus, 2018), pictured in Figure 2 below. These goggles fully envelop the user’s eyes in a black box, excluding the surrounding environment from the user. The goggles are usually suspended with straps that pull the goggles tight against the user’s face, and another strap over the head, holding it in place. There are usually two displays, one for each eye HMD, producing a stereoscopic view [ref?].

![Figure 2 – Left: Oculus Rift (Oculus, 2018), right: HTC Vive (HTC, 2018)](image)

Another variant are glasses. These have see-through capabilities, allowing the user to see the real world in addition to the virtual elements that the glasses present. The information is either displayed on the see-through glass in front of the eye, on a display next to the eyes, or directly onto the retina in the user’s eye. Examples of the three types are Glass (X, 2018), Vuzix Blade (Vuzix, 2018) and Intel Vaunt (Bohn, 2018), respectively, of which two are shown in Figure 3 below.

![Figure 3 – Left: Glass (X, 2018), right: Vuzix Blade (Vuzix, 2018)](image)
Glass-type HMD’s exist in several variations, for instance ones that have larger projection areas in front of the eyes, more like a visor. An example of a visor HMD is Microsoft Hololens (Microsoft, 2018), shown in Figure 4 below. It is not supported by rims on the ears as normal glasses, but instead has a helmet-like hold that is put on and around the head. The Hololens also have greater computational power than Glass and Vuzix blade, but to the cost of greater weight.

Figure 4 – Microsoft Hololens (Microsoft, 2018)

3.3.1.2 Handheld devices
A handheld device is any sort of device that a user holds and operates with one or two hands. While devices that are developed and engineered for a specific purpose exist, most handheld devices are either mobile phones or tablet computers. Both specific and generic devices have their purposes. Specific devices can be tailored for the application, meaning it is possible to equip it with any technology that is needed. This enables the device to have greater processing power, cameras and other sensors, and be designed for the specific purpose. Generic devices such as mobile phones and tablets are available off the shelf, are equipped with a lot of functions such as cameras, gyroscopes and accelerometers, and a touch screen, at a cheaper price than a tailored device. (Nee, et al., 2012)

3.3.1.3 Projectors
Projectors can be used to display an augmented reality to users without forcing them to wear HMD’s. Depending on the projection solution, the user may still have to wear some equipment, however. This is because projection solutions can be categorised into fixed installations and portable installations, where the portable installations are carried by the user. (Nee, et al., 2012)

3.3.1.4 Cave automatic virtual environment (CAVE)
A CAVE is an immersive virtual reality environment. Large projection screens in the size of walls make up a room where the virtual environment is displayed on the screens around the user (Cruz-Neira, et al., 1992). This requires the CAVE to be smaller than the room it is located in, as the projectors displaying the environment needs to be outside the CAVE walls. However, in modern CAVE systems the walls can instead comprise of large displays (Onime, et al., 2016). As the user is put into a virtual environment and still able to see their real body and not a render of it, a CAVE should more reasonably be called an AV experience and not a VR experience. (Onime, et al., 2016)

The CAVE has three to six of its sides projected, where more sides give a more realistic simulation, therefore a better experience for the user. However, a user in a CAVE cannot fully utilise it unless they put on a pair of stereoscopic glasses that give the user a full sense of depth
These glasses are not a full headpiece like goggle-type HMD’s, but similar to regular glasses that the user can see through. Stereoscopic glasses come as either passive or active. For use in a CAVE the glasses have to be active, which alternate between blocking the view of the left and right eye. The projectors in the CAVE display a stereo image where the first frame is for one eye, and the next frame is for the other eye in a repeating pattern. The glasses are synchronised with this pattern so that the both eyes only get the frame meant for it. This creates an illusion that tricks the user’s brain into seeing the view in depth. (Creagh, 2003)

3.3.2 Tracking and registration

In order to create the feeling of realism in a virtual environment, the user’s actions have to be tracked. Tracking user’s actions in the real environment enables displaying these as corresponding actions in a VR environment. One of the most important tracking devices for VR systems are pose sensors. These track the position and orientation of the user in the virtual world. However, only tracking position and orientation is not enough for a most VR environments. The user’s motion is also a key component to track. (Mihelj, et al., 2014)

There are several principles for tracking a user’s movements, such as mechanical, ultrasonic and optical principles. One of the most common principles is triangulation based on structured light. To track the motion of an object using triangulation, the object is first highlighted with light arranged in a pattern, hence the name structured light. When the light touches the object, the pattern gets distorted. Simple patterns using straight lines turn in to curves when projected onto the object. The light pattern can then be analysed and the shape of the object to be determined using mathematical algorithms. Other patterns, such as a dotted pattern, can be used to determine distances of objects or their depth. Illustrations of patterns are shown in Figure 5. (Mihelj, et al., 2014)

Using the position, respective depths of surfaces, and relative distances of the object and its different parts, it is possible to track the pose or motion of an object or person (Mihelj, et al., 2014). An implementation of this system is in the tracking units or base stations for HTC Vive, also known as “Lighthouses”, because of them flooding the room and the user with invisible light
Another tracking example is Leap Motion, an IR sensor system that tracks the user’s hands and displaying their movements on any kind of display.

Accurate tracking and registration is a basic enabling technology that is also fundamental for AR systems to work properly. In an AR setting it is important for real and virtual objects to be merged seamlessly, which is impossible to do without accurate tracking of the user’s movements. Tracking for AR has historically been done using hardware, but as the need for simpler, smaller and less bulky equipment has risen, software-based tracking has increased in use to the point where it is now the favoured method. (Nee, et al., 2012)

By equipping a device with a video camera and analysing the captured images, it is possible to estimate the camera’s viewpoint, and thus the device’s and the user’s viewpoint too. The existing and commonly used algorithms for tracking and registration can be classified into three different categories: marker-based tracking, natural feature-based tracking and model-based tracking. (Nee, et al., 2012)

A marker is a unique shape or pattern that makes them easily detectible and distinguishable in the environment, see Figure 6 below. Fiducial markers are frequently used in AR applications, as marker-based tracking is a reliable and stable method. However, it requires some form of preparation as the marker has to be placed or previously exist in the environment. (Nee, et al., 2012) As the marker has to be easy to identify, it sticks out from the surrounding environment and takes away some of the realism that the simulated environment is trying to create. By using DR, it is possible to obscure the marker, thus increasing the blend of virtual and real environment again. (Mori, et al., 2017)

Most natural feature-based tracking is using robust point matching to enhance the stability and the increase the tracking range. Unlike marker-based tracking it can also be used for tracking of objects in an environment that is not prepared in advance. Model-based tracking is making use of features recognised and detected by that natural-based tracking instead of fiducial markers. The detected features are matched with known and previously determined features in CAD models, such as geometry, dimensions, texture and motion. (Nee, et al., 2012)

3.3.2.1 Haptic technology

Haptic technology enables a user to experience the sense of touch from a virtual environment. Haptic devices use vibrations, forces or movements to provide the user with touch feedback from the virtual environment. The perception of touch is split into cutaneous and kinaesthetic sensations, thus dividing haptic technology correspondingly into tactile feedback and force feedback. (Deng, et al., 2014)
Tactile devices stimulate cutaneous receptors in the skin. Such stimulation includes texture, pressure, friction, roughness, shape, temperature and puncture. The simplest variant of feedback is vibrations, such as a vibrations signal in a mobile phone. While this feedback can be regulated to vibrate with more or less intensity, in certain intervals or in specific patterns, it only provides a general and unspecified feedback to the whole device and cannot provide specific feedback to buttons or triggers. (Deng, et al., 2014)

However, feedback where the feedback is not only simple vibrations, but the feedback also affects the user’s movements is called force feedback. Such feedback is kinaesthetic and emulate motion, force and position. This type of feedback is commonly found in simulators, where the physical equipment behaves and responds according to what the simulation does. (Deng, et al., 2014)

But haptic devices do not only provide the user with feedback. Some devices make use of tactile sensors to measure the force that a user applies, send it to the simulation which adapts to the input force. (Mihelj, et al., 2014)

3.3.2.2 Handheld controllers
Handheld controllers differ from, for example, mobile phones in the sense that the controller’s main purpose is to work as input to and output from an application. Simple handheld controllers have one or several grips for the user to hold onto, and buttons, trigger or joysticks for input. More advanced variants have tactile sensors for registering applied force and movements, accelerometers or gyroscopes to track the users’ movements, or microphones or cameras to record sound and visuals. (Mihelj, et al., 2014)

Some handheld controllers also provide the user with direct feedback. This is usually done in the form of a visual display providing information, or vibrational feedback. The vibrational feedback is usually general, meaning that the whole controller vibrates and not specific parts of it. Also, force feedback is generally not available in common controllers. In return, most handheld controllers are relatively cheap and widely available. (Mihelj, et al., 2014)

Common variants of handheld controllers are the wand-type, which the user grips and points like a wand. Two examples of handheld controllers are the Oculus Touch and the Vive controller, pictured in Figure 7 below.
3.3.2.3 Other haptic devices
There are other methods of tracking and interacting with VR and AR environments apart from haptic controllers. Vests and jackets have been developed for greater stimulation (Deng, et al., 2014), and full body suits are emerging (Teslasuit, 2018). There are also gloves that provide very precise and accurate stimulation for the user’s hands (HaptX, 2018), see Figure 8 below.

![Haptic glove](image)

Figure 8 – Haptic glove (HaptX, 2018)

Apart from general haptic devices, there are also specialised devices for specific purposes. Steering wheels with force feedback have been available for simulators and video games for a long time, and haptic chairs and seating pads also exist. (Deng, et al., 2014)

3.3.3 Gamification and serious games
Games are generally associated with being an entertaining leisure activity. Users of video games, usually referred to as “gamers”, commonly describe gaming as a fun and entertaining experience, providing challenges, motivation and rewards. (Dörner, et al., 2016)

Traditionally, most video games were played on a PC or using console connected to a TV, where the user base were boys and young men. But this description is no longer valid. Games are more accessible as they are now playable on mobile phones, tablet computers and smartwatches, while the PC, TV connected consoles, and other traditional formats are still available. This has changed the market and turned it into a market that has something for all sorts of users. (Eklund, 2016)

As video games have become much more accepted and prevalent in society, principles and elements from game-design has been applied to contexts that historically have nothing to do with video games. This concept is called “serious games”, where the main purpose of the game is not to entertain the user, but instead being educational and pedagogical, while maintaining the core aspects of gaming by being challenging and fun for the user. Recreating real-life scenarios and placing the user in these virtual scenarios provide unique possibilities that would not be possible in the real world, or would in some way be dangerous or difficult to achieve. (Dörner, et al., 2016)

Serious games are used in all sorts of education and training purposes, and within many different industries, including automotive and manufacturing. (Dörner, et al., 2016)
3.3.4 Health and ergonomics

3.3.4.1 Simulator sickness
Simulator sickness, or cyber sickness, is a common ailment when using virtual reality equipment, especially head mounted displays. The sickness is caused when the user is moving their head, and the images displayed in the HMD is not responding quickly enough. This causes a delay between the user’s actual movement and the user’s perceived vision of the movement, the change in viewpoint in the HMD. The differences are confusing the user’s brain, trying to handle multiple different impressions, thus causing sickness. (Brooks, et al., 2010)

3.3.4.2 Eye-sight and corrective lenses
Google-type HMD’s for virtual reality have the monitors placed close to the user’s eyes. This requires the eyes to focus on a short distance, which will strain the eyes after prolonged exposure in a session. (Brooks, et al., 2010)
4 Comparative studies

This chapter presents and summarise the cutting-edge technologies in the different sub-categories within the field of virtual reality. It also describes how a few competitors are working with these technologies.

4.1 Virtual reality

4.1.1 Visualisation

One of the most important aspects of virtual reality over viewing on an ordinary monitor is being able to view the visibility a person has in a certain posture or position. Such analysis is difficult in a desktop application, as the natural movement of a person in the simulation gets lost, while VR is well suited for such tasks. Situations where these types of analysis are useful are for evaluating driver positions or how changes to a product affect its assemblability. (Berg & Vance, 2017)

By recreating the real world in a virtual environment, it is possible to perform actions that are impossible in the real world. Results of computational fluid dynamics (CFD) calculations can be loaded into a VR world, where a user could see flows of media that are otherwise invisible to the human eye, such as currents or turbulence. (Berg & Vance, 2017) Such information can be helpful in optimizing placement of outlets, while also considering aesthetic aspects. (Ostermann, 2018)

4.1.2 Design

Using VR for designing purposes gives several benefits. It is possible to change any aspect of the product's feature, functional or aesthetic, and study how these changes affect the user and their reactions. Using VR design, it is therefore also possible to test the product, evaluating different options and validating these options before making a physical prototype. As making physical prototypes is often very costly and takes time, both a lot of money and time can be saved in development projects when using VR for designing purposes. (Mihelj, et al., 2014)

When designing an interface, it is not only important to put effort into aesthetics, but equally important is the ergonomics of the interface. While VR is useful for evaluating the viewpoint of the user, it can also be used to understand how the user is moving or changing their posture to reach or manoeuvre a certain component. Several concepts can be evaluated simultaneously to better understand how placement affect the ergonomics for the user. Similarly, VR can help in evaluating where instruments should be located to be most easily viewed and accessible depending on the situation. (Berg & Vance, 2017)

VR simulations usually require input from external supplies, such as pre-modelled CAD files and pre-defined environments. There are some tools that allow for creating 3D data in a virtual environment, usually creating surfaces from the users' hand movements. At least one tool is able to extrude surfaces from a 3D sketch, thus enabling going from a sketch to a volumetric model. (Ostermann, 2018)

4.1.3 Robotics

VR has been used with great success to teleoperate robots. This is useful for reprogramming robots when workpieces or fixtures are redesigned, or if the robot workstation layout has been changed. Another area where VR have been useful in robotics is programming and workspace planning. A virtual robot is controlled by a haptic-based controller, and the virtual robot's movements are reflecting the real-life controller and its movements. (Nee, et al., 2012)
4.1.4 Factory Layout Planning
In the field of factory layout planning (FLP), VR has been used to solve planning and layout tasks. Several commercial products offer similar services, namely a simulation software for the plant or factory. These provide a realistic visual representation of the planned factory and also allow the user to refine the plans using built-in design tools. The systems are not made for doing the whole design from scratch, however, but require 3D models to be pre-designed in other tools. (Nee, et al., 2012)

4.1.5 Training
One particularly widespread discipline within VR is training and different forms of education and teaching. Two-dimensional imagery is limited as it lacks depth. Using VR this is corrected, and it is easier for the student to get a better understanding of the subject as it is possible to not only view the object in three dimensions, but interact with it and see it function in its environment. Using VR for training purposes makes it easy to understand the spatial relations between objects and functional units. (Mihelj, et al., 2014)

VR has also been proven useful to train persons in situations deemed hazardous or where physical training would be impossible or impractical. Simulators have been frequently used in different industries for different purposes for a long time, and VR simulators have only increased their usefulness. (Mihelj, et al., 2014)

4.1.6 Meetings
Virtual reality gives the possibility to meet other people in a virtual meeting room, no matter where they are physically located. Using different techniques, the meeting attendees could be represented by a replica of themselves – avatars – be it either a realistic depiction of them or not. Meetings could either be where all users are participating, or where some users merely observe other users’ actions. Similarly, cooperation between users is possible where the actions of each user is fully visible to the other users. (Mihelj, et al., 2014)

4.2 Augmented reality
4.2.1 Assembly guidance
Assembly guidance is a term describing methods of helping assembly operators in their work. A guiding system using AR helps operators perform tasks or operations that require a higher level of qualification or skill than they otherwise would possess. (Wang, et al., 2016)

In its simplest form, assembly guidance would provide the operator with step-by-step instructions (Wang, et al., 2016), by displaying them in the operator’s field of view. This would enable the operator to keep attention on the assembly operation, thus saving time and reducing the risk of errors (Ong, et al., 2008). For step-by-step instructions in AR to be usable they have has to have a real-time connection to the progression of the assembly. However, very few systems have been shown to keep track of the assembly progression, distinguish errors from non-finished steps and recognise when the assembly is complete. (Wang, et al., 2016)

CAD data can be used in an AR device to visualise instructions. An interactive 3D model could be presented to the user, along with written instructions and animations guiding the user. (Wang, et al., 2016)
4.2.2 Assembly training
AR can be used for training purposes, where it could be the main educational tool or a support for a teacher. Most AR education is based upon a predefined procedure with a number of set steps. It has been shown in many studies that learning by using AR tools or as support is very effective and that the test subjects complete their tasks much quicker and with fewer errors than regular training. (Wang, et al., 2016)

One major challenge of AR training is that direct feedback that is formulated and adapted to fit the user and their results, is virtually non-existent. Without systems where teachers or expert operators could supervise the students and help them in their learning, the training system would be limited. (Wang, et al., 2016)

4.2.3 Assembly process simulation and planning
In the task of simulating and planning assembly processes, AR has been shown to be of use. Virtual objects can be visualized in the assembly process, with them having flexible reactions to events and situations. Information about the objects’ position and orientation in the assembly is also possible. AR has also been used to show the spatial relationship between parts and components in an assembly. (Wang, et al., 2016)

4.2.4 Robots
AR has been used to address human-robot interactions and robot programming issues. This is done by giving the operator intuitive interaction tools for controlling the robot, and then displaying the virtual robot’s movements that mirror the real-life robot. Programming could also be done by an operator guiding the robot with a marker that the robot is tracking. The programmed path could then be validated in a virtual scenario to verify that the path is free of obstacles and no collisions occur. (Nee, et al., 2012)

4.2.5 Factory layout planning (FLP)
Similar to simulating an assembly process, there are tools for factory layout planning. There are several FLP systems using AR. The system allows the user to add virtual objects and lay them out in the real environment. Such applications are often collaborative in nature, to allow multiple users to see the same virtual objects and environments, thus increasing the common understanding and consensus. (Nee, et al., 2012)

4.2.6 Maintenance, repair and service
Like assembly guidance and training, AR can be used to guide and train service technicians to perform tasks that they have not yet learned or are not qualified for, or are seldom performing. AR can present instructions for the user while still allowing them to use both hands. Another benefit is the possibility of connecting to a remote user who can guide and assist in the operation. (Nee, et al., 2012)

4.2.7 Challenges using augmented reality
A few issues and challenges are common for many AR applications. (Nee, et al., 2012)

To track a real object in real-time is often difficult. Several methods for tracking exist, including using cameras, positioning systems like GPS, and inertial tracking techniques such as accelerometers and gyroscopes. One or more of these methods are used depending on the situation, setting and location, and the needed precision. High-precision application need hybrid-solutions, often including inertial tracking techniques and computer-vision, or RFID tracking where movements are too quick for cameras to process. (Nee, et al., 2012)
The next problem is superimposing augmented images or information onto the tracked object. Orienting the virtual object correctly and placing it on top of the real object is called registration. Different methods of tracking or registering an object exist, and are suited for different applications depending on the object itself, it’s surrounding, movement etc. This is also the cause for two types of errors connected to registration: static and dynamic. Static errors are caused by inaccurate sensors, alignment between sensors or by registration algorithms that are not working properly. Dynamic errors are often attributed to delays and slow computational equipment, which cause problems in synchronisation and latency in streams of data. Latency is also a problem in displaying the augmented data. (Nee, et al., 2012)

Marker-based tracking systems require the observing sensor, most often a camera, to see the marker at all times. If the marker is blocked, the AR overlay may jitter or disappear completely. It is also a potential issue to mark the all the observed parts. (Nee, et al., 2012)

4.3 Diminished reality
Technology providing a diminished reality can be categorised into four different functions: diminishing, see-through, replace and inpaint. Diminishing serves to downgrade the visual information that is served to the person, meaning that the person’s perceived image is in some way distorted. It could be that an image is acquired by the technology, processed so that it is blurred or thinned out before it is presented to the user. (Mori, et al., 2017)

The see-through hides objects in the real world with images that corresponds to the object’s occluded background. This makes the object seem invisible to the user. (Mori, et al., 2017)

Replacing is a function to put a virtual object on top of a real object, so that the real object is replaced by the virtual object. For this to work properly, the virtual object has to be equal or larger in size than the real object. Alternatively, it is possible to first perform the see-through function on the real object and then replace it with a smaller sized virtual object. (Mori, et al., 2017)

The last function is inpaint. This function takes in the surroundings of the real object to create a virtual background that is similar to the real background of the real object. (Mori, et al., 2017)

One common drawback of using diminished reality functions is that there are inaccuracies between the background and the hidden object, making it obvious to the user that there is an object obscured from their vision. (Mori, et al., 2017)

The majority of existing methods for creating diminished reality are using stationary equipment. These have cameras fixed in space, enabling better rendering of realistic diminishing of objects, while not enabling any mobility. There are only a handful of cases where diminished reality is used in HMD’s, and the most of these are used in entertainment systems. (Mori, et al., 2017)

4.4 Competitors
As Scania is a part of the Volkswagen Group, several opportunities for competitor comparisons presented itself. One of Scania’s closest competitors and collaborators, MAN, held a presentation at Scania on how MAN’s engineering department is working with VR.

A study visit to Volkswagen in Wolfsburg was made. The purpose of the trip was to visit a part of Volkswagen Group’s development labs and meet people working with innovation in the fields of virtual reality and augmented reality.
4.4.1 MAN presentation

Two representatives from MAN held a presentation on how they are working with AR and VR. MAN is organised in hierarchical pipe structures, where each pipe has its own support functions. Boris Koller, represented the IT department supporting the engineering branch, where engineering is referring to research and development engineering and design. Koller’s specific area of expertise is within visualisation tools. To understand the need for VR and AR within the organisation, a request was sent out to all employees asking to come up with ideas and use cases where VR and AR could be beneficial to the working processes or the products. Out of almost 800 suggested ideas and use cases, only four were deemed to have such a benefit that it was possible to create a solid business case based upon them. MAN is currently utilising power walls, google-type HMD’s and CAVE’s for VR. (Koller & Herold, 2018)

4.4.2 Study visit at Volkswagen

Volkswagen is one of the world’s largest volume car manufacturers. Its headquarters and main facilities are located in Wolfsburg, Germany. (Volkswagen AG, 2018) Volkswagen also has one of the largest research and development divisions within the automobile industry. In order to quickly respond to changes in social conditions and trends, Volkswagen has setup a sub-structure within research and development. This sub-structure is called Group Research and has the mission of anticipating the customers’ future needs and translate these into innovative new technologies. Group Research does research for all of the brands within the Volkswagen Group. (Volkswagen AG, 2018)

One part of Group Research is a lab structure focused on IT innovation and development. This lab structure is a network of labs spread out over the whole world. Each of the labs have a certain focus area. The two labs located in Wolfsburg are the Smart Production Lab and the Virtual Engineering Lab. The Production Lab is focused on projects within production and logistics, while the Virtual Engineering Lab is working with projects within the research and development area. The labs are divided into several development teams with around five members each. Each team is assigned to one proof of concept (PoC) project, which is sprung from one idea. (Ostermann, 2018)

The ideas that are incubated in the Virtual Engineering Lab have to be related to the research and development sectors of Volkswagen Group. Both ideas related to the group’s products, product development and tools for employees are valid to enter the list of potential project candidates. A project is allowed a maximum development time of twelve weeks before it is evaluated. If there is value in the result, the project is handed over to the ordinary development process that turns the PoC into a complete software and manage it. Rejected PoC’s are discarded and not evaluated further. All ideas that have been processed through the labs are registered to keep records of what has been done to not revisit old projects again. (Ostermann, 2018)

Volkswagen has a tool to quickly draw and create sketches in VR, and from those lines create surfaces to make surface models fast and efficiently. The tool has multi-user capabilities and is deemed to be the best for its use case. The Virtual Engineering Lab has also developed a tool and environment to evaluate completed styling concepts by letting a person be in the drivers’ seat and inspect and interact with the environment. (Ostermann, 2018)
5 Scania

Scania is manufacturer of heavy trucks, buses and coaches, and engines for industrial and marine applications. Its headquarters and main facilities are located in Södertälje, Sweden, with additional plants in Oskarshamn and Luleå. Globally Scania has factories located in Zwolle in Netherlands, Anger in France, São Paulo in Brazil, Lahti in Finland and Slupsk in Poland, along with several smaller production units located around the world. Supporting their production is a network of retailers, distributors and service centres spread all over the globe. (Scania AB, 2018)

Since 2015, Scania is fully owned by Volkswagen Group, and a part of its truck and bus subsidiary together with MAN Trucks and Buses, and Volkswagen Caminhões e Ômnibus. (Scania AB, 2018)

5.1 Product description and modularity

Like many other automotive companies, Scania works with modularisation of their products. However, the way Scania thinks about modularisation differ from many other manufacturers. Scania laid the foundation to its modular system in the late 1940’s. Further work in the area led to modularisation becoming a business strategy for the company in the early 1960’s. Continuous work to identify and analyse stresses that affect the different components in the trucks resulted in what was Scania’s first fully modular product range. (Scania AB, 2015)

One of the fundamental aspects of the modular way of thinking at Scania is to always try to reuse parts when possible. A designer at Scania first have to investigate if there are existing parts that suit the purpose. While there may not be exact matches, similar parts could be adapted to fit both the old and new application, and thus replace the old part. If it is not possible to reuse the part, or it deemed impractical or unsuitable to do so, a new part is created. With this mindset, Scania has reached a modular system with a very fine level of granularity, where even the range bolts and washers are accommodated. (Flodmark, 2018)

The product description is a term used to refer to all types of data and documents pertaining information on Scania’s products. This include part numbers, drawings, revisions, standards, CAD models, geometries, how models (and therefore parts) are positioned, rotated, and connected and related to each other, assembly drawings and much more. The system used to archive drawings and models is a PDM system called ENOVIA, provided by Dassault Systèmes, while other product description data is stored in another PDM system OAS, which is an in-house developed system. (Flodmark, 2018)

Scania has found their own way of structuring their data, that is different from how other companies do it. Many other car and truck manufacturers use a model-based system, where each model is predefined by the company and only allows a few variants. While Scania offer similar options for the customer, the customer’s choices does not correspond to a certain part and BOM. Instead, the customer’s choices is saved as a string of variant codes, each describing the options the customer selected. The customer variant string is translated into a technical variant string, unique to the specific customer order. This technical variant string is then compared to a validation structure to confirm that the options the customer selected are valid in combination with other options. This means each order is different and not connected to a particular part or BOM. (Flodmark, 2018)

Scania uses a generic product structure to describe their products. This structure can be described like a tree, where the trunk is the main component (i.e. a truck, bus or engine). The further up the
tree, and the further out on the branches you look, the finer is the detail. The leaves on the tree are single, individual part numbers, while the branches can be seen as components, or sub-assemblies, consisting of several parts. (Flodmark, 2018)

This structure is the same for all of Scania’s products and thus contains all parts and all executions imaginable. To make this functional and useful, each level in the tree-hierarchy is coded with technical variant codes where needed. This enables filtering of the product structure, in turn allowing different customer specifications to use the same structure. For example, every truck needs at least one front axle. This level would not have any restricting technical variant codes. However, at the level under this, there would be two new branches. One branch would be for trucks with only rear-wheel drive and the other for trucks with all-wheel drive, therefore having a driven front axle as well. Depending on how the customer specified their order, the product structure would be filtered to either of the branches, but never both, as no truck can have both all-wheel drive and only rear-wheel drive. The same methodology is applied to all levels in the tree where there are several options. If only one option exists, no rules are specified, as this option is valid for all variants. Branches that are incompatible with other options, thus making them invalid, are coded in such a way that they will not be highlighted in a filtering, while some are compatible and are highlighted. This way, multiple sub-branches may be possible for each branch. An illustration of how Scania’s product structure looks is shown in Figure 9 below. (Flodmark, 2018)

By composing the product structure this way, Scania is not limited to a number of pre-configured variants, corresponding to a part number representing a complete BOM. This makes the structure very flexible and allows Scania to fully adapt their products to the customer’s needs.
However, a full BOM is harder to produce for Scania, as each BOM is a result of filtering the structure according to a customer’s specifications. (Flodmark, 2018)

### 5.2 Software
A company as big as Scania has a large amount of software at their disposal. Some applications and platforms are central to its operations, however. To organise all product description data, Scania uses the in-house developed PDM system OAS. It holds all information about the product structure and part relationships, part positions and rotations, and much more. (Wejde, 2018) This is explained further in chapter 5.1.

For product development design, Scania mainly use a platform from Dassault Systèmes. This platform includes the CAD tool CATIA for designing and ENOVIA, a PDM tool. ENOVIA keeps track of status and revisions of CAD documents. It also allows Scania’s engineers to collaborate on part design by restricting access to change the file to only one person at the time. (Wejde, 2018)

A subsystem called GEO visualises parts in their correct positions on the product. Depending on what the user wants to see, they can choose to show an entire product, a component, such as an engine, cab or axle, or level in the generic structure. Doing this will present the user with all of the parts the selected level and below, possibly causing a cluttered view or a view that is unable to load because of its size. A better way is to perform a “breakdown”, which is a filtering of the hierarchical structure. In a breakdown, the user can specify to use a certain part of the structure by selecting certain technical variant options, thus excluding unwanted components and parts. It is also possible to base a breakdown on a specific customer order or product. (Wejde, 2018)

GEO is used both for visualisation of the current products and to use as reference for in-position designing of new parts. It gets the part structure, or BOM structure, part position and part rotation from OAS, and present the hierarchical structure in ENOVIA. The user can then choose what from this structure to present visually in CATIA. (Wejde, 2018)

The latest version of the platform (v6) is a large brand portfolio called 3DEXPERIENCE (3DS), but Scania has yet to fully transition to this version. Currently, the only v6 application Scania is using is a vPDM system to archive drawings, technical documentation, matrixes and other product data, and present it via a web interface to its employees. Other applications in the platform, i.e. CATIA and ENOVIA, is still in version v5. (Wejde, 2018)

When ordering a breakdown, a user has the option to choose between four different output formats: native CATIA format and three different lightweight formats for different uses. Examples of differences in the lightweight formats are how accurate they are in representation, such as polygon reduction algorithms or removed surfaces.

### 5.3 Observations on organisations within Scania
The following chapter describes some groups and organisations within Scania, how they work and their current status relating to virtual and augmented reality. All sub-chapters are based on interviews with employees in respective groups and organisations. As different interviewees have different knowledge, some supply knowledge of their area of work, while others also provide insight into the field of VR and AR. Therefore, the level of detail in each sub-chapter varies and this chapter is to be regarded as a both survey of Scania’s status, as well as additional theory in the subject.
5.3.1 Research and development

Scania has a process for its product development work, simply called “the PD process”. All product development is run through this process, but depending on where in the lifecycle the product is, some stages are left out. The process is divided into three separate stages: yellow, green and red. The process flow is continuous, as each stage provides input to the next stage. It is visualised as several curved arrows that forms a circle, see Figure 10 below, where each stage is highlighted in its respective colour. (Bonde, 2018)

![Figure 10 – Visual representation of Scania’s product development process (Scania Project Office YP, 2013)](image)

The first stage is the yellow stage. This is a concept phase where new ideas are born and formed. The concepts can spring from many different forums and sources. It could be a strategic vision to change or upgrade an existing component or platform, or create a new from scratch, to meet with new customer demands or a new market. Laws and regulations are also a major initiator of new projects, as these often impose a strict deadline that Scania need to adhere to in order to continue selling their products in certain areas. Another possible concept initiator is experience from previous product development projects, where ideas were brought to light, but did not fit into the scope of that particular project. Such ideas could instead be discussed in a yellow arrow forum, to be determined if it is worth taking further in the process. It is also possible that representatives from Scania’s production, be it either machining workshops or assembly lines, request from the research and development branch to investigate new products or solutions to problems to be able to increase efficiency, productivity or quality in production. Similar requests could also come from the purchasing department or aftermarket representatives, extending requests from suppliers or service workshops. Regardless of how the concept was initiated, it must be prepared before a decision on its future is taken. This preparation is usually a pre-study that determines what is to be gained by introducing the concept, expected profitability, estimated duration for the project, need of resources and more. Most of all, this pre-study is done to eliminate risks in the future project. When preparation is done, the concept is brought up for discussion in a forum to determine if it is good for development or if it is scrapped. (Bonde, 2018)
When a concept has been decided to be substantial enough to develop further, it is either packaged on its own or with similar concepts into a project and moved to the green arrow stage of the project development process. This stage is the longest stage in this process, and it is in this stage that all the major research and development occurs. A project manager is assigned to the project, and every project is split up into sub-projects called “objects”. Departments within the research and development branch are assigned an object corresponding to their designated area of responsibility, for instance the gearbox, engine or axles. For each object, one or more design engineers are assigned. These design engineers have specialisation areas within their department and can therefore be assigned to several projects simultaneously, if their specific competence is needed there. A lot of employees in different roles are also assigned to the project, apart from the design engineers. Stakeholders, such as purchasers and suppliers, production engineers, aftermarket specialists and more, are brought into the project as needed and are responsible for their respective areas. It is common in production to have an assistant project manager; whose assignment is to handle the project for the specific production area. (Bonde, 2018)

While the yellow stage of the product development process develops initial concepts for the project, it is up to the design engineers to come up with how these concepts should take form and handle any problems that this might bring. These suggestions and solutions are often discussed with other design engineers who provide feedback and input to changes. It is, however, not equally common that early ideas and solutions are discussed outside research and development. (Bonde, 2018)

There are several steps in the process where interactions between stakeholders is needed or decisions have to be made. For instance, there are five mandatory points in the process where the new product should be test assembled. The time leading up to and during these test assembly occasions require interaction between the responsible design engineer, the production engineer, the purchaser and likely others. While direct communication between people is common, the official information carrier is a document called an Engineering Change Order (ECO). It holds all information on what project it is, what parts are introduced, changed or discontinued, what changes the project brings and how the parts are interconnected with each other and current parts. (Bonde, 2018)

The ECO holds information on the parts and drawings that are connected to it, but does not hold the drawings themselves. These 2D drawings are stored as PDF-files in a digital archive. Scania has historically been using 2D drawings as their defining part document, and not 3D models. However, a project to make 3D models the defining part document is currently ongoing. (Wejde, 2018)

5.3.1.1 NTQD – Product Engineering Transmission
Scania’s research and development unit is divided in a hierarchical branch structure, where each branch is responsible for different modules. One branch is responsible for the powertrain development, to which the group NTQD belongs. Their responsibility is to handle design assignments in the red arrow part of the production development process on transmission components and parts, such as gearboxes and central gears for rear axles, along with many of their interior parts like gears. (Bonde, 2018)

NTQD and its sibling groups are currently not using VR or AR for any application whatsoever. Some areas could likely be improved, however, as many of them cause trouble or delays in the daily work already. This mainly relates to communication problems where people have different views or opinions of a matter, causing unnecessary argumentation. Some examples are where
information or problem description has to be shared between people in different departments and countries, where technological expertise and language differ. Similarly, trouble often occurs when a customer cannot fully explain the problem with their product that has broken down in the field. (Bonde, 2018)

At a certain point in the red arrow process is a critical step, a milestone, where a thorough conceptual solution has been developed for the assignment. This milestone is a checkpoint to verify that the conceptual solution is good enough for realisation. The solution is presented to a steering group or deciding organ, who decides if the assignment is prepared enough or not. This is done in a meeting room using a projector and Powerpoint. (Bonde, 2018)

After the concept is decided, further designing and engineering takes place. When the part is close to being finished, prototypes are created, and the prototype part is tested in physical test assembly. This is costly and cannot be performed until late in the development, when the concept is soon finished. To counter this problem, parts are sometimes tested virtually in digital test assembly using a tool called Delmia. This tool can simulate assembly of a part in its virtual counterpart of the physical assembly line. This tool is complex and has to be managed by a trained employee to be able to show relevant results. It is, however, limited to be presented on a normal monitor. Virtual test assemblies are not always performed, as it requires knowledge that the design engineer does not possess and due to time constraints in the projects, this step is sometimes skipped. (Bonde, 2018)

5.3.1.2 RCDI – Driver Vehicle Interactions

The group called RCDI – Driver Vehicle Interaction is responsible for driver interactions in the cab of the truck. Driver interactions are how the driver use the inside of the truck cab, what interfaces there are, and how they are positioned and designed. (Krupenia, 2018)

To the group’s disposal is a 3D lab with several tools and equipment. There is an advanced simulator built around a real Scania cab. Three monitors positioned outside and around the cab shows the outside environment, and the two side mirrors have been replaced with two smaller monitors that show a rear-facing view. The group also use HTC Vive for some VR applications, such as simulating interactions between the driver, the truck and an urban environment. For all types of dynamic simulations, low-resolution images are used in favour of increased responsiveness from the simulation. Other types of applications use high-resolution images, however. One example of this is a static VR environment with a static truck where the user can walk around the truck, looking at it from any angle, but also enter the cab and sit in it as a driver would. The user can then move the mirrors and interact with some parts of the dashboard, similar to what a driver would in real life. Unlike most other groups at Scania and the Volkswagen Group, RCDI is not using Unity for their simulations. Instead, they favour using Unreal Engine as it gives better visual quality. (Krupenia, 2018)

As RCDI is not an engineering department, but focusing solely on design and driver interactions, its members do not use CATIA or ENOVIA in their work. While they could get this data from engineering groups, it would be cumbersome and there would always be a waiting time attributed to it. Adding to this would also be the process of cleaning and lightening the files before use, which is usually time-consuming. This means that they have no simple way of performing breakdowns of products on their own, having to rely on other methods to get their model data. (Krupenia, 2018)
5.3.1.3 RCDE – Physical Vehicle Ergonomics

RCDE is responsible for the physical ergonomics in the cab of the truck. Their task is to create optimal conditions for the driver, minimise injuries and the risk of traffic accidents, while both the inside and outside of the vehicle are functional and easy to operate. (Jönsson, 2018)

Designing lighting for a cab can be difficult as there are many factors that come into play. Different light sources produce different types of light. Incandescent light bulbs, fluorescent lights, halogen lights and LED all produce light at different temperatures, providing light suitable for different applications. Deciding what light source is appropriate for a certain application can therefore be difficult. (Jönsson, 2018)

But not only the light source itself makes a difference. The armature and its design also play an important part, as does its positioning and orientation. Another factor is the surrounding environment, with external light sources, materials and textures. To develop new lights for the interior of a cab thus requires a full cab, or at least creating a prototype of an isolated interior. Physically building a setup by using production parts is expensive, even more so if using prototype parts as these are usually one-offs, often requiring special tools or machining. Even while producing a physical setup, it is impossible to make a quick comparison between different lighting options. This is due to that only one lighting configuration is possible per setup, as other fixtures may interfere with how the light spreads and looks. Another problem is that a physical setup is often not up to date, as many parts and even products change radically during the product development process, thus maybe causing results of the experiment to be invalid or not up-to-date. (Jönsson, 2018)

A master thesis project is currently ongoing, soon nearing its completion, investigating a process of using virtual reality to solve this problem. In a VR environment it is possible to always use the latest CAD models of the interior, making the setup current and its results usable. A VR environment also enables the user to be standing in one location and exchanging the surroundings. This means that it is possible to create several different setups for the lighting, placing them in the exact same position relative to the user and hiding all but one at the time. Utilising this method, the user can quickly switch between the different variants and see what lighting option is better suited. For the thesis, Unreal Engine is used. (Jönsson, 2018)

However, lighting is one of the trickiest parts of creating a simulation using a game engine. It is a time-consuming work as the user has to create UV lightmaps for each part. A UV lightmap stores lighting information for a part or an object in the virtual world. While it is possible to use exclusively dynamic lighting, this has a great impact on performance as the computer has to render the lighting constantly, while a UV lightmap is static, thus having a minimal impact on performance and usually produce a better visual result. The UV lightmaps are unique to each project in Unreal Engine, and therefore has to be recreated every time a new project is started. (Jönsson, 2018)

5.3.1.4 RCDS – Styling

The styling department have several different groups, all responsible for styling in some way. These groups design the “A surfaces”, meaning all surfaces visible to a person standing beside the truck or sitting inside the cabin, which in turn dictates the boundaries for the rest of the engineering design. A group called RCDS – Styling is responsible for creating high-resolution pictures of Scania’s products and put them in a context. Examples of this could be a long-haulage truck with a trailer on a highway, a garbage truck in a city or a heavy-duty truck in a mining environment. (Forsberg, 2018)
The pictures RCDS are creating are often used in marketing purposes, where there is need to reach out to customers at an early stage in the product development process. A result of this is that many of the parts on the products are not yet parts in serial production or even finished in design. But as the products need to at least look complete in the pictures, parts are often machined to fit that specific product, providing form and looks, but not function. The process of creating single parts for one-time use is costly and time-consuming. (Forsberg, 2018)

Digital tools have developed over time and is now capable of producing photo realistic images from solely digital 3D models. This has enabled RCDS to produce their content quicker and cheaper than before. By using only digital models it is also possible to view the results in a virtual reality. RCDS use mainly two software for their visualisations purposes; VRED and Deltagen. The two have different strengths and weaknesses and are thus suitable for different types of visualisations. Deltagen is capable of handling very complex models with advanced underlying structures, making it suitable to visualise different variants in Scania’s detailed generic structure, such as variations of a complete engine or even a truck. It is, however, a very advanced tool to work with, and getting it to display its result in a VR setting is very hard. Conversely, VRED is capable of visualising in VR with the push of a single button, thus making it easy for the user to see the object in a realistic environment. However, VRED does not support structures in the same way as Deltagen does, and therefore any imported model with structure will be locked to that specific model, and thus cannot be configured to display multiple variants using Scania’s generic structure. Both VRED and Deltagen can be used to visualise an object in a static VR setting, but not interact with it, as they are both visualisation tools and not simulation tools. As VRED is a simpler tool than Deltagen to use for a designer without specific engineering competence, while also producing a superior visual result, it is the preferred tool for RCDS. (Forsberg, 2018)

Other groups in the styling department produce the styling models, creating the A-surfaces that RCDS use in their visualisations. As this design is an early part of the product development process, it is not part of Scania’s product description or generic structure. While the A-surfaces are connected in a structure, this structure has no connection with the design structure that is used for describing the product. This means that RCDS cannot use the generic structure for their work, instead having to rely on the structure created by the stylists or create their own, which can be a time consuming task. (Forsberg, 2018)

5.3.2 Production – transmission assembly

Scania produces rear axles for their trucks and buses in two factories, located in Södertälje, Sweden and in São Paulo, Brazil. The facility in Södertälje also houses lines producing front axles, central gears for driven axles, tag axles and gearboxes, with two additional lines for development and testing of axles and gearboxes respectively. As driven axles, central gears and gearboxes are all part of the transmission of a truck or bus, the whole facility is commonly collectively called “transmission assembly”. (Entezari, 2018)

5.3.2.1 DTOA – Rear axle assembly line

The rear axle assembly line has a total of 30 workstations, divided into four work areas, but is also split into two segments. In the first segment, the work stations are stationary during the tact, while the second segment is a continuously moving line. (Entezari, 2018)

The first of the four work areas correspond with the first segment of the rear axle assembly line. It has ten workstations, each called “pallet” in singular, which have given the segment its name “palettbanan”. Each “pallet” is stationary during the tact, instead moving in the beginning of
each new tact. The flow of this segment is not straight as a line, instead having a U-shape, condensing the needed space and ease the return flow of empty pallets. (Entezari, 2018)

Rear axle housings, the main body of a rear axle, are sequentially ordered in racks in the first position, where the positioning corresponds to the planned sequence of orders. The rear axle housings are lifted onto the pallet on the first station, and a unique assembly order is printed on paper that follows the individual axle through the whole assembly process. A transport yoke is mounted on the axle to enable lifting and transporting the axle. (Entezari, 2018)

The main purpose of “palettbanan” is to make assembly of the central gear easier, as the rear axle housings are tilted to expose the mounting position of the central gear. The interface between the rear axle housing and the central gear is a stud screw and a nut. First, the stud screws are screwed into the rear axle housing, then the central gear then lowered into position, aligning holes in the central gear housing with the stud screws in the rear axle housing. Finally, the joint between the central gear and rear axle housing is tightened with flange nuts. (Entezari, 2018)

A robot turns the axles the right way up after the central gear is assembled, and the axle is put onto a carrier using the transport yoke and the axle is carried onto the “TMS-line”. The second work area mainly deals with parts and components on rear axles with drum brakes, while having almost no work on rear axles with disc brakes. Next to the line is an area preparing a sub-assembly component package that is feeding into the line by manually pushed carts. Sharing the same space as the sub-assembly area is a picking area, where additional drum brake components are picked according to a separate picking order sheet, which is individually printed for each axle. Another pre-assembly area is located further downstream, directly connected to the line. This station fits brake chambers with unions and connections for all axles with drum brakes. The raw brake chambers are not stored along the line, but delivered in sequence from a separate picking area in another part of the plant. (Entezari, 2018)

The third work area is focused to work on the hubs on the axles. A sub-assembly area produces two hubs for each axle, which are then fed directly onto the line. Parts for axles with additional gear reduction in the axle ends are mounted if needed, before the hubs are mounted and tightened with a large nut runner. (Entezari, 2018)

While the second work area is assigned most parts for axles with drum brake, the fourth work area is mounts and assembles the majority of the parts for axles with disk brakes. Brake callipers are delivered in sequence to the line and mounted on axles with disk brakes. This work area has a station that mount unions and connections in brake chambers for all rear axles with disc brakes. This station, unlike the subassembly station for brake chambers for rear axles with drum brakes, is directly connected to the line and has both storage of frequent brake chambers, as well as a sequential flow of infrequent brake chambers. (Entezari, 2018)

As the fourth work area is the last work area on the whole rear axle assembly line, it also finishes the assembly of the axle. Drive shafts are delivered in sequence from a separate picking area and mounted on all rear axles. Hub reductions and drum brakes are mounted on axles when needed. All rear axles are then pressurised to check that they are airtight before they are filled with oil. Lastly, a final inspection is performed to verify that the correct parts are assembled and that critical joints are tightened. (Entezari, 2018)

5.3.2.2 DTL – Logistics

Logistics are a complex subject and is much more than a support function to the assembly lines. While the logistics department does indeed feed the line with material for assembly and transport
the finished products to its customer, it requires an extensive and tightly run logistics network to do so. Many people are employed to man the transmission assembly’s forklifts, tow tractors, and kit stations that supply the assembly lines with material. Added to the logistics network is structure of logistics developers, material and production planners, and others, who support and develop the infrastructure and methods.

When an axle is finished and to be delivered to the customer, it is put in a rack with a standard mounting position. To hang the axle on the rack, a lifting yoke is needed. The rack is the same for all axles, regardless of size and weight, but the yoke differs between different types of axles. There is about ten different yokes in total and some are more commonly used than others, as certain types of axles are more common. All yokes are part of a loop, from where they are mounted on to the axle, transported along with the axle to its’ customer destination, removed from the axle and put in a pallet for later sorting, sorted and then returned to the axle assembly again. Because of the number of axles produced every day, axles in transit and in buffers at the transmission assembly and at the internal customers, and yokes in buffers, the amount of transport yokes needed is very high. (Brandtieng, 2018)

To make handling of this loop as simple as possible, the variants of yokes are kept at a minimum. A new yoke is costly to add to the loop, and changes to the yokes that are frequently used is even more expensive, due to the sheer amount of yokes that need modifications. Changes to the transport rack is even more costly, as these are used for every single axle produced. The transport racks are thus an extra limitation that has to be accounted for when new axles are developed. The design engineer should verify that the axle fits inside the boundaries of the transport rack. However, equally important is to verify that the transport rack can hold the weight of the axle. It is therefore important to verify that the weight of the new axle does not exceed the limit of what the transport rack can hold. Today this is done using the part weights available in OAS. This information is unfortunately not always accurate, thus giving incorrect total weights. Apart from the racks holding the axle, the transport yokes have to keep the axle balanced in both the transport rack, but also on the assembly line and in the axle paint shop. Therefore, the centre of gravity is important along with the weight of the part. Then it is possible to calculate the total weight and centre of gravity for the axle, making it possible to evaluate the new axle in the current transport racks and yokes. (Brandtieng, 2018)

Several different groups at Scania are working with developing internal logistics solutions. Some are tried and tested at the transmission assembly. One example of an AR applications is a pick-to-voice system, where the material handling employee is wearing some kind of headphones, in which an automated and pre-recorded voice tells the material handler what part number to pick and the quantity. The material handler then confirms when they are finished by pushing a button on the glasses. Another example, which is not tested at the transmission assembly but in Scania’s SMART factory lab, is a pair of glasses. These glasses show the material handler where to go, using a list of items to be picked as input. The glasses point to the pallet and highlights it, and the material handler has to manually confirm that the item has been picked by making a hand gesture with a special glove that registers the movement of the material handler. (Brandtieng, 2018)

The logistics development group is currently not working with any 3D models in their projects. All their work is based on 2D drawings made in LayCAD. One reason for this is that 2D is considered much more time-efficient than making models in 3D (Brandtieng, 2018). When planning the layout of materials in shelves and racks, the group uses Excel. They have made the
cells’ heights and widths to scale of the standard shelves and racks used, and also made scale models of standard boxes and pallets used in the transmission assembly. (Brandtieng, 2018)

A transfer to 3D is needed, and while it is possible, it would be very time-consuming (Brandtieng, 2018). Using a VR environment would be useful to plan the factory, and through that get a much better understanding of how everything fits together. An even better step would be to be able to simulate the flow of the logistics network, to be able to time it, synch transports and deliveries in the network, or ride along in a forklift. (Brandtieng, 2018)

5.3.2.3 DTOBM – Axle paint shop

All axles are painted after assembly is finished. This is done in an automated paint shop in the same facility as the assembly lines. The axles hang on conveyor to maximise the exposed area and allow for the most amount of freedom around the axles. The axles are first washed and dried before paint shop employees manually mask areas of the axles that should not be painted. After masking the axles are separated into two automated painting lines, both of which are capable of painting all axle types. One of the lines has an additional manual paint booth where custom colours are added for customers requesting this.

Each line has two automated paint booths, one for primer and one for top-coat paint. One booth houses four paint robots, positioned in a zig-zag pattern with two robots on each side of the axle. The axles move continuously through each paint booth and each robot is responsible of painting roughly a quarter of the axle.

All robots have programs that tell them how to move and when to do certain actions. New or changed programs are programmed in a certain robot test booth and then uploaded to the robots in the painting booths. The robot test booth is connected to the main conveyor system of the paint shop, which means it is possible to utilise other parts of the facility, such as the washing, before sending the axle to the robot test booth. But having the robot test booth connected to the main conveyor system also means that it can take a long time to get an axle into the test booth, as it always has to pass some part of the complex conveyor system. It is also not possible to turn or change position of the axle once it is in the robot test booth, and as such it has to be sent out in the paint shop to change direction. Additionally, the robot test booth contains only one single robot and not four as in the paint booths in the paint shop line. (Andersson, 2018)

When a new program is developed, a complete axle is needed. The robot programmer has to physically move the robot to its correct position, rotate the arm and the tool and then save the coordinates and rotation amount for the specific process step. This is then iterated until all parts of the program is complete. The robot can calculate trajectories between points, but it cannot detect any obstacles in the way. That means that the robot programmer has to take this into account and adjust for this, making the programming even more tedious. As the robot test booth only has one robot, and the axle has to leave the booth and come back to be turned around and expose the other side to the robot, new programs take a long time to create. For a new type of rear axle where a completely new program is needed, programming is estimated to take one person 120 hours. (Andersson, 2018)

5.3.2.4 DTMB – Product development in the axle assembly

Being centrally located, the Södertälje transmission assembly is internally considered to be the “leading workshop” for axle assembly, meaning it has the lead role of testing new products and providing feedback from production into product development projects. (Entezari, 2018)
The development line for axles is not a full-size line, mirroring the main lines for the respective product types. While it does have both a fixed workstation and a conveyor to replicate the workstations on the rear axle assembly line, it is not connected to the main assembly lines and all axles have to be transported by forklift. Furthermore, the development line does not have all specific equipment or tools that are available on the main lines, and space is limited. However, much of the equipment on the main lines serve to reduce use time and ensure that the end result is meeting the wanted quality, and it is therefore possible to replicate much of the main lines’ capabilities by using simple tools, such as spanners or torque wrenches. Other equipment on the main lines have backups that can be used for shorter periods on the development lines, allowing for more accurate representation of the normal work flow. (Entezari, 2018)

In product development projects, new concepts are often discussed and evaluated using mock-ups or plastic parts made with rapid prototyping techniques. These tests are commonly performed on the development lines and using current parts, products, tools and equipment as references. At later stages, test assemblies using prototype parts with materials that match the final part are carried out, to ensure that everything fits together in the correct way. New tools and equipment is also verified to work properly during these test assemblies, so that they can undergo modifications if anything needs to be adjusted. As a last verification, all products are then tested in the main production lines. These verifications serve to test the full processes, with logistic flows, line balance and that installed tools and equipment behave as expected during extended use. (Entezari, 2018)

When new equipment and tools are purchased, either for product development projects or for regular upgrades of the current setup, Scania request that the purchase also include documentation of the tool or equipment. This documentation shall always include drawings describing the purchased product and a description on how it is to be used. While 3D models of the equipment and tools are getting more common, and are usually requested with new purchases, much of the already installed equipment and tools only have 2D drawings available. (Entezari, 2018)

All industrial engineers in the transmission assembly are required to update a registry of all currently used equipment and tools. They are also required to update a digital layout of the factory which shows all where stationary equipment is fixed and where loose tools and equipment are used. The layout is possible to present in 3D, but many of the height values are incorrectly set to 0, meaning that even in a 3D environment much of the surroundings would be flat on the ground, essentially making it a 2D drawing. (Entezari, 2018)

The accuracy of the layout is also uncertain, as the layout is maintained by many people. The more changes there are, the greater the risk of errors being put into the layout. In contrast, while the industrial engineers responsible to update the layout should do so whenever a change is complete in the real factory, this does not always happen on time. It is also not certain how precise the placement between the different items in the layout is, or how accurately the layout of the rear axle aligns with other parts of the facility. (Entezari, 2018)

In addition to the manually created layout, a scan of the rear axle line has been performed. This was done as part of master thesis project in 2013. This scan produced a point cloud presenting a 3D view of the rear axle line. (Svedberger, et al., 2013)
However, as many projects have affected the physical layout, and thus the digital layout, of the rear axle line since 2013, the scan is likely no longer accurate enough to be used. No new scan has been done and there is currently no known plan to do so. (Entezari, 2018)

5.3.3 Global production engineering

Scania has a global production engineering department whose responsibilities are to perform research, develop and innovate the field of production engineering at Scania. Another of its assignments is to assist production workshops and local industrial engineering groups and bring expertise in their projects. The department has several different groups with different focus areas and the group members being experts in their respective fields. One of these groups is TEI, who work with shopfloor IT. (Hanson, 2018)

TEI has previously worked with AR applications using the Hololens. The results from these tests proved to be unsatisfactory and where therefore not put in production. As of the writing of this report, TEI is currently working on developing a SMART factory lab that will be fully up and running within a year. The SMART factory is also being replicated in a virtual factory environment with workstations, material shelves and racks, and tools and equipment. The virtual factory allows multiple users to participate in the production of a pedal car. Each station has all materials and tools needed to produce one pedal car, and is therefore not an assembly line. However, it could work as a non-continuous assembly line with some changes to the environment. As the virtual factory aims to replicate a real factory, it keeps track of the number of products assembled and products with errors. It also has a has an automated guided vehicle that travels around the virtual factory in real-time, replicating the path and movement by its real-life counterpart. (Hanson, 2018)

It is TEI’s goal to fully simulate the correct assembly process of one or all of Scania’s factories. But in doing so, there are many hinders to overcome. Some the major findings are that that the pedal car is not in ENOVIA, making it impossible to accurately simulate the process from engineering to production. (Hanson, 2018)

TEI have also initiated collaborations with MAN and Volkswagen by trying out their technology or by borrowing VR tools and testing these. One example is the utilisation of MAN’s CAVE, where virtual test assemblies of trucks were conducted. One example of a tested VR software is a tool where the user is placed into a simulated workstation and assigned to assemble parts on the car. The simulation provides a realistic environment along with an unfinished car, and an assembly station with parts and tools. It is then the user’s tasks to assemble the correct parts in the correct place on the car, using the correct fasteners and tools. The purpose of this VR software is to demonstrate or visualise a new product before it is physically available. (Hanson, 2018)

Another example of a VR software is the production planning tool. This tool shows a virtual version of a real factory or plant in a life-size scale for the user. The user has the possibility to import all kinds of production equipment, logistics equipment and parts and place them in the virtual factory. This software is thus used to plan a factory layout and provide a realistic view of how it could look when finished. As the software has support for multiple users, it can also act as a tool for visualisation and evaluation. (Hanson, 2018)

The factory planning tool has not only been tested in laboratory conditions, but also for real projects. When the transmission machining workshop was to be upgraded, TEI helped the local industrial engineering teams and logistics developers by visualising the workshop in VR and
thereby helping with planning the factory. Another example of where VR has been used extensively is in Scania’s new foundry. This huge project requires extensive planning, and for this purpose was used to plan and layout the new foundry interior. (Hanson, 2018)

There is currently another master thesis project ongoing at TEI. One of the main missions of this project is to evaluate different SDK’s for VR development and compare them to today’s practices at Scania. One of these evaluations is to use Unity to create a simple virtual environment and load one of Scania’s products or components. The demonstrated example was of a tandem of rear axles with their hierarchical tree structure intact from the breakdown in the generic structure. This provided a full model of the two rear axles, also allowing to make the individual parts interactable. A simulation such as this could be used for training purposes or visualisations during digital test assemblies or design reviews. This specific setup took 15 minutes from start to finish, with no or little prior training in Unity. The models were imported using the PiXYZ plugin, which simplifies the raw CAD models into a lightweight format where only surfaces remain. This simplification took around an hour, but when finished, the Unity files can be saved into .prefab files which are quick to open. (Tolman, 2018)

5.3.4 YSPX – Service Support Solutions

The group YSPX – Service Support Solutions are responsible for developing service and maintenance solutions for the aftermarket. One solution that is currently in end-testing is a remote guidance tool. The principle for a remote guidance tool is to give the service technician a camera, likely in a pair of smart glasses or a tablet or mobile phone, to be able to film the area that they need assistance in. The video feed is connected to a service centre or directly to a senior technician who can evaluate the situation and provide assistance to the field technician. The field technician receives directions from the senior technician on their capturing device, usually as an overlay on the video feed or some sort or as verbal guidance. (Malmkvist, 2018)

This started as a master thesis project four years ago and has evolved from there. The then currently available computer software was adapted to Google’s platform and the field technician wore a pair of Google Glasses. Through these, they could send a video feed of the problem area and receive guidance and assistance directions on the Glasses’ display. The results were promising, why a more developed solution was needed, and external developers were contacted. XM Reality was contracted, as they already had a solution suitable for Scania. (Malmkvist, 2018)

At the time, XM Reality used to develop their own smart glasses for their solution (Malmkvist, 2018), but has now partnered with smart glasses manufacturers ODG and Vuzix instead (XM Reality, 2018). XM Reality’s solution is to provide remote guidance via visual overlays on the field technician’s mobile phone or tablet. The field technician connects to a service centre via an app, then proceeds to view the problem area by video on their device. The service support technician sees the same video feed and is through it and voice communication with the field technician diagnose the problem. The service support technician can then guide the field technician by voice and using a “pointpad” (XM Reality, 2018), which is similar to an overhead projector that can be used to point in the video feed or show documents to the field technician (XM Reality, 2018).

The solution provided by XM Reality is fully mature and is ready to implement fully at Scania if so was desired, but currently there are no directives to do so (Malmkvist, 2018). However, even though the available solution is functioning, there are still functionalities that could improve it further. There is currently no support to show information regarding the specific product that is being repaired. Such support would enable getting different documents, such as CAD models or electrical schemas, from ENOVIA and 3DX and apply information from them into an
augmented reality. The field technician could then see the parts they needed to change or repair as highlighted or contoured in the AR application, or see how cables are routed on the chassis. (Malmkvist, 2018)

Apart from YSPX, no employees from other groups working with service in any form have been interviewed.

5.3.5 Purchasing
Scania’s purchasing branch is the S-branch. It is responsible for contracting suppliers for all raw material, parts, components and non-automotive products from external suppliers. While there are many departments responsible for procuring items for certain Scania components, it is possible to generalise and divide the purchasing work into two processes connected to the PD process. The first process is the “forward sourcing” process, where raw material, parts and components for a new Scania product is procured. It is connected to the green stage of the PD process. The second process is the “commodity sourcing” process, where the project has been handed over from the green arrow of the PD process to the red, meaning that the Scania product is in full-scale customer production.

The group SEF – Project Purchasing Forgings is responsible for all suppliers and procurement of forgings for powertrain parts and components in the forward sourcing process.

The forward sourcing process is divided into seven steps. The first step is a preparation step to compile all material regarding the procurement. All technical documentation is gathered along with what suppliers that will get a request for offers.

5.3.6 Marketing
The K-branch at Scania is responsible for all types of sales and marketing.

5.3.6.1 KTIE – Product Engineering
The group KTIE is responsible for creating images of Scania’s products for marketing purposes. A small team of three people is working with different digital tools to achieve photo-realism. The input comes from Scania’s CAD data, usually as breakdowns of specific products so that the structure and correlation between the parts are obtained. However, the data has to be lightened and “cleaned” before it is usable. This is due to the large file size of the raw CAD data, which requires a lot of computing power to be able to handle when adding light, reflections and similar, as is required when creating photo-realistic images. As only surfaces are visible in most images, only the A-surfaces and connection interfaces/surfaces need to be kept to hold the structure, and thus the product, are required. Material added for structural reasons can be removed, as can functions such as gears or wires, unless they will be visible in the image. Apart from lightening the model, the team also often have to correct the data as design engineers do not always save models properly. Some documents may contain hidden layers or parts that become visible when importing the document to other software, multiple models in the same document, incorrect export to the GEO system, or incorrect usage of modelling commands that result in erroneous models. (Sahlin, et al., 2018)

The lightening and cleaning of documents is done in Deltagen. After opening a document, it is compared with previous versions of the same document using a special plugin. This plugin compares the different versions to determine if there is a difference between the versions, and the user is then able to take action based on the comparison. When the files have been lightened
to the wanted polygon count and/or file size, it is exported to other formats, such as .fbx or for use in other software, such as Maya. It is also saved in the Digital Garage. (Sahlin, et al., 2018)

The Digital Garage is a project with the purpose of creating models of common Scania products and provide these models in different formats. The idea is to speed up work by providing a range of products that has enough information in their different executions to be able to be used by most employees at Scania that need models, no matter if it is for simulations or visualisations. Currently, the Digital Garage is not available for everyone within Scania. One of the reasons for this is that there has been no good distribution system until recently, when the KTIE team discovered and decided upon using Picturebook. This is a product directly linked to Deltagen, where it is easy to upload the reworked models, while also having a catalogue web interface which provide easy access for users to access the models. (Sahlin, et al., 2018)

The digital image team at KTIE has three main customers within Scania. One is the product configurator, which is a tool that is able to show different executions of the product that the customer wants. It visualises the customer’s choices and shows how certain options affect other options and executions. The configurator tool needs both images of parts and products, but also images where certain parts are highlighted or contoured. As this tool need to be fast, the images have to be smaller, why photo-realism is not optimal and good-looking digitally created images is used instead. A second internal customer use is the product data. This is support for the sales organization, and is used to illustrate the products for customers and requires more realism. The third main internal customer is for commercial images. This group provide images of Scania’s products for commercial purposes, such as marketing and brochures, why photo-realism is a must. (Sahlin, et al., 2018)

The process of lightening and cleaning CAD models for other uses is time consuming and a largely manual work. CAD models are often not done correctly, why there is a lot of cleaning unnecessary information and fixing broken geometries and model steps before the models can be lightened. There are automatic tools available for lightening models – a method called “jacketing”. This method is based on the tool guessing what surfaces are A-surfaces and B-surfaces, working from this to remove what it considers unnecessary data. The tools are often not clever enough and the produced results are generally not satisfactory. Such a tool could be used as a first step, however, thus decreasing the time a person has to work with the file. (Sahlin, et al., 2018)

5.3.6.2 Sales training
An event aimed for Scania’s sales personnel was held during the autumn of 2017. This occasion was a sales training event where VR was used. (Eriksson, 2018) I have not been able to find out, who was responsible for the event and what equipment and data was used. However, the data is likely to have come from data that KTIE has processed (Sahlin, et al., 2018).

5.3.7 Other
5.3.7.1 Hackathon
Scania has arranged an internal hackathon for its employees in December for the last few years. During these events, Scania employees are invited to showcase their innovations that they have worked on in their spare time. One examples of this is an augmented reality app for visualising frame holes.

The frame of the chassis are two large U-shaped beams. These are tilted to their sides with the opening inwards toward the other beam. The beams are connected with cross beams to make up
the basic framework for the chassis of the truck. On the faces of the beams pointing to the side of the frame are frame holes. The frame holes are modular like much of Scania’s products and the frame hole pattern thus differs from chassis to chassis depending on the what the customer has ordered. Most of the frame holes are the same dimension and are arranged in a mostly symmetrical pattern. This allows for the modularity, as some holes are used for certain things on one chassis and for another purpose on another chassis. Rivets are mounted in the frame holes to lock other parts and components in place. Not all holes are fitted with rivets from factory, however, as bodybuilders use some of the frame holes for their assemblies. Because of this, and because the holes look alike and are arranged as they are, it is a very difficult job for an assembly operator to mount rivets in the correct holes for the specific chassis. It requires much training and experience to be able to properly mount the rivets the first time, why there are two senior operators whose only assignment is to correct rivets that have been improperly fastened. (Persson, 2018)

One example of a solution using AR and Scania’s product description is the “Frame hole app” created for the [HACKATHON EVENT]. The user places a marker in a specific and easily identified spot in the frame hole pattern. Then the user opens up the app on the workshop tablet and enters the specific chassis number and the app puts a request to OAS to make a breakdown using the product specification. This breakdown filters out the parts and components that are to be fitted to the specific product, along with the frame hole pattern and rivets. The user can then track the marker in the frame hole pattern on the frame and project rivets in the correct frame holes corresponding to the specification and what is to be fitted further downstream on the assembly line. The app also allows the user to project what counter-face parts are to be mounted, to give the user a better understanding of why which rivets are mounted, thus also providing a teaching experience. (Persson, 2018)

5.3.7.2 IT at Scania

Scania has a branch dedicated to IT. The branch is responsible for all matters directly related to IT, such as infrastructure, in-house development of software, support, and specifying and providing hardware solutions. A large number of computer configurations are available for order, but only the most recent edition of the “Advanced Workstation” (AWS) is powerful enough to use for VR purposes. The AWS is equipped with a nVidia Quadro P5000 graphics card which is certified for CATIA. (Krupenia, 2018)

Scania is providing HTC Vive through its external supplier of computer hardware. To be able to utilize the Vive, which requires Steam, the user have to get added permissions to bypass the firewall, proxy and get administration rights to the computer.

5.3.7.3 General observations

When displaying models in VR it is common to only display the surfaces, as a VR environment is demanding for the computer to display. While RCDS mainly use A-surfaces for their visualisations, even these can be too complex to render smoothly, i.e. in perceived real-time, in a VR environment. As A-surfaces are the lightest format available at Scania, this is what RCDS usually work with. But for complex visualisations, this is not enough. The models have to be lightened even more, meaning that the polygon count has to be decreased. A full CATIA model can contain around 20 million polygons, while around half a million polygons are the threshold for running a smooth simulation in VR. Scania currently does not provide any models this light, and users requiring such models have to lighten them themselves. Lightening a model usually
involves removing the insides of the model, leaving an empty shell comprised of all the visible surfaces. One of the most common lightweight file formats used in VR is .fbx. (Forsberg, 2018)

Lightening procedures can be done by RCDS, but is often not enough for a VR environment. To provide models that are light enough for VR, external software is needed. Examples of software capable of lightening models for VR use are Simplygon, InstaLOD and PiXYZ. However, the number of polygons is likely a problem soon to pass. As computer performance increase and the game engines improves, it will be possible to smoothly render more polygons in a VR environment, removing the need for lightening of models. (Forsberg, 2018)

Another option to visualisation tools such as VRED or Deltagen is to use game engines (Forsberg, 2018). Two modern game engines capable of providing VR support are Unity and Unreal Engine, based on C# and C++ respectively. Unity has a wider user base at Scania and is also the preferred and standardized game engine used by Volkswagen. It also has a large community of users outside of Scania, which is a useful source of information. Unity has less advanced graphical capabilities compared to Unreal Engine and is less powerful overall. Because of this, Unreal Engine is used by some groups at Scania that need the best graphical results as possible. (Krupenia, 2018).

5.4 User experiment and survey
In order to better understand the threshold of VR equipment for new users, a simple experiment was conducted. All employees at YMSC and its neighbouring groups located in the same building were invited to test a HTC Vive by playing one game and using one application, and those interested were booked for a test session.

The demonstration was set to 30 minutes per person. Each person got a quick presentation of the controller, its functions and buttons along with a description of what they would experience.

5.4.1 Demonstration
Two different software were used in the demonstration. These were selected based on four criteria:

- Available for free use on either Steam or Vive portal.
- Stable release from a professional developer.
- No inappropriate content for a work environment.
- Provide experience similar to what a Scania user would have in their daily work.

The first software chosen was a game in form of an interactive story called “Star Wars: Droid Repair Bay”, where the user is playing as a mechanic repairing robots. This game makes use of the Steam controllers to move the mechanic’s arms, which only have a simple gripping mechanism. The game presents what the user has to do by another mechanic pointing and demonstrating, without the use of any text or spoken language. As the game is an interactive story, it has a set duration of about 15 minutes. In this time, four robots have to be collected via a crane controlled with a joystick by the user, then repaired and then an optional test run where the user directs the robot via a tool similar to a laser pointer. The setting for this game is similar to what a real-life novice mechanic would experience in a workshop, making it a suitable game for the experiment.

As for the second part of the experiment, a simple, yet versatile 3D modelling software called “Blocks” was used. This software gives the user the ability to create a set of pre-defined shapes
(cones, spheres, cubes, cylinders and toruses), which the user then can modify by gripping and pulling and pushing nodes, lines or surfaces into a new shape, extrude surfaces or sub-divide them. The user also has the ability to draw strokes, paint shapes and surfaces, snap shapes together. Other features include zoom and rotation, and import of models and pictures into the session. The application provides a tutorial in which the user learns the basic commands. This tutorial was used for the experiment to provide all participating users the same start. When the tutorial was completed, the users were free to design whatever they wished. However, all participants were given directions as to what tools to use and when to use them, to make all participants go through the same steps.

5.4.2 Surveys
To evaluate the experience, two separate surveys were used. The Simulator Sickness Questionnaire (SSQ) (Kennedy, et al., 1993), see appendix B, was used to understand if users experience any type of simulator sickness during the simulation. Results from the SSQ are quantified and aggregated to show an average and a standard deviation from the average. Another questionnaire was developed for this specific test and was aimed to understand more about the user and the experience in general, see appendix C.

A form for external evaluation of the user’s actions, need for assistance and perceived immersion was developed and used during the tests. The purpose of this form was to give a comparative observation of how different people behave and react to a realistic simulation, and not only get the user’s response on how they experienced the simulation. See appendix D.

All participants were introduced to the surveys before conducting the test, and verbally agreed to the conditions of their use.
6 Results

The concept of virtual reality has been around for almost a century, but it is just in recent years that the development has reached a level that has allowed the technology to become powerful enough to provide a genuinely realistic experience, while maintaining a low enough price to attract a large group of customers.

High-end personal computers are very powerful today. A gamer or a serious enthusiast can purchase a VR ready computer for a reasonable amount of money, and a VR kit for even less. Scania’s IT department offers several different computer setups, but only one that is capable of handling the requirements of a VR environment.

6.1 Analysis

The most important aspect to regard in analysing potential uses for AR and VR at Scania is whether there is need for AR or VR, or just any digital tool. As all forms of AR and VR studied in this thesis need some sort of more or less cumbersome equipment, it is very important to decide which use cases that are suitable for AR and VR, and which are not. Some determining criteria has to be set in order to be able to separate use cases that may need AR or VR technology, from those that can be resolved using simpler equipment. For this purpose, some close-ended questions can be ordered in a flow-chart.

The purpose of the flowchart is not to serve the user with a definitive decision, but to provide a model to discuss and base decisions on. While the flowchart seemingly proposes to use alternative solutions to AR and VR where the alternative is sufficient, this is not necessarily true. The steps in the flow chart are intended to encourage to investigate the matter further, not to
make a quick decision. All solutions must be investigated before following the arrows to another box in the flow chart.

6.1.1 User experiment
Results from the user experiment is shown in Table 1 below. Full results from the simulator sickness questionnaire, general experience survey and the observation form are presented in Appendix E, F and G respectively.

Table 1 – Table of results from general experience survey

<table>
<thead>
<tr>
<th>Question</th>
<th>Number of responses</th>
<th>Average (0-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you used VR before (more than 10 minutes)?</td>
<td>8</td>
<td>0,3</td>
</tr>
<tr>
<td>What was your overall impression of VR before the session?</td>
<td></td>
<td>3,1</td>
</tr>
<tr>
<td>What was your overall impression of VR after the session?</td>
<td></td>
<td>4,4</td>
</tr>
<tr>
<td>How real did the simulation feel?</td>
<td></td>
<td>3,9</td>
</tr>
<tr>
<td>How intuitive was the simulation?</td>
<td></td>
<td>4,0</td>
</tr>
<tr>
<td>In general, how well did you feel after the session?</td>
<td></td>
<td>4,6</td>
</tr>
<tr>
<td>Were you afraid during the simulation?</td>
<td>5</td>
<td>0,2</td>
</tr>
<tr>
<td>- Tripping</td>
<td>9</td>
<td>0,3</td>
</tr>
<tr>
<td>- Colliding</td>
<td>13</td>
<td>0,5</td>
</tr>
<tr>
<td>- Teased by other person</td>
<td>1</td>
<td>0,0</td>
</tr>
<tr>
<td>- Touched by other person</td>
<td>2</td>
<td>0,1</td>
</tr>
<tr>
<td>How was the picture sharpness?</td>
<td></td>
<td>3,7</td>
</tr>
<tr>
<td>Do you use corrective glasses or contact lenses?</td>
<td>15</td>
<td>0,5</td>
</tr>
<tr>
<td>- Did you wear corrective glasses or contact lenses when using the headset?</td>
<td>11</td>
<td>0,3</td>
</tr>
<tr>
<td>How comfortable was the headset?</td>
<td></td>
<td>3,6</td>
</tr>
<tr>
<td>How adjustable was the headset to make it comfortable?</td>
<td></td>
<td>3,8</td>
</tr>
</tbody>
</table>

The results from the user experiment show that the users were very impressed with virtual reality overall and their ratings of impressions rose significantly from before trying to after. It also shows that the demonstrated applications are both realistic and intuitive. Picture sharpness is judged to be good, as is comfort and adjustability of the headset. However, external observations showed that the intuitiveness was not as good as the users themselves reported and guidance was needed frequently.

Even though the user experiment showed that most users felt comfortable using the equipment and the situation at large, some felt bothered by the possibility of being touched or teased by others. It should also be noted that the experiment was conducted in a separate room where only the participant and the observer were present, which likely skewed the results in favor of users being comfortable. Observations from trials in an office area, where user tests similar to the user experiment were performed, are that people are wary of their surroundings and more people were afraid of being touched or teased by bystanders. Situations where bystanders were touching or teasing the person using the VR equipment also occurred several times.

6.1.2 Health and ergonomics
6.1.2.1 Simulator sickness
The survey from the users’ general experience showed that most users felt well after the simulation, as the average ratings from the general were high. The SSQ showed similar results
where the ratings for nausea were very low, with oculor-motor ratings at a low average as shown in Table 2 below.

\[
\begin{array}{|c|c|c|}
\hline
\text{Average} & \text{Nausea} & 1.07 & 1.40 \\
\text{Standard deviation} & 1.20 & 1.54 \\
\hline
\end{array}
\]

Table 2 – Average and standard deviation calculated according to the Simulator Sickness Questionnaire

6.1.2.2 Eye-sight and corrective lenses

No concrete studies or information has been found regarding how virtual reality and augmented reality equipment is affected by wearing corrective contact lenses, especially glasses. However, the user experiment showed that all participants that use corrective glasses or contact lenses during the test were able to use them without problems, thus enabling them to have the same experience as a user not wearing prescription glasses or contact lenses. It should be noted that several users complained about not getting a sharp image, regardless if they were wearing corrective lenses or glasses, or not.

6.1.2.3 Movement

Users generally move much more than they would in a real-life environment, based on the observations of users in the experiment. While the average score for natural movement is rated highly, this is because of that the movements themselves are natural-looking, but the sizes of the gestures are larger and more exaggerated than they would be in real life.

6.2 Possible implementation areas

6.2.1 Production

Before an operator is allowed to assemble on customer orders, they could be trained in a VR environment to learn every manoeuvre, what tools to use and so on. This would allow for training workers in controlled settings without risking quality defects that would need rework in a real setting.

The assembly order could be presented to the assembly operator by AR glasses instead of on paper as it is currently. Similarly, instructions for each step of the assembly could be visually or audially presented to the worker. It would then be available to the operator at all times, helping to ensure quality and that standards are followed correctly.

When an assembly operator picks a part for assembly, it must be verified that the part is the correct one for the specific order. As this is done manually by eye, it is possible that errors occur. Using AR glasses for this to both verify that the part matches both the denoted content on the pallet and that the part is mounted correctly on the axle would not only eliminate picking errors, it would also eliminate the need for a final quality check of the component or product as the assembled parts are guaranteed to be correct for the order.

When the part is picked, AR could also be used for helping the operator choose the correct tool to fit the part to the axle.

For a robot programmer, VR could be a useful tool. This would allow for an intuitive environment where they could move in a virtual world without risk of being struck by the robot when it is moving. Using VR for programming would also allow for earlier programming than is
possible today. Having fully representative CAD models showing the axle, the programmer could paint the axle with a VR controller and software could calculate the optimal painting routes based on the path the programmer registered. Such software would allow for programming much earlier than is possible today.

On a larger scale, VR and AR could be used when designing the factory. When designing a factory from scratch, VR would be a useful tool to get a full grasp of the scale of the factory. It would be a simpler task for the project manager to convince steering groups of a layout when the members could enter the factory themselves and see it as if it was real.

When buying new machines or equipment to a factory, AR could be used to show the new machine in its setting. This way, it would be possible to consider the exact environment around the machine that might not have been considered otherwise. Regulations and already installed equipment affect the other machines’ surroundings, possibly by intruding in the space the new machine would take up. Such collisions and similar simple errors would be easy to detect using AR.

Product development in production could make use of both VR and AR. Showing how a new part or product would look in its real environment with AR is a good way of getting a common understanding of what is being developed and how it is affected, and affects, the production plant. VR could be used for the same purpose without requiring the users to physically be in the factory.

6.2.2 Logistics
The potential for implementation of VR and especially AR in logistics is great. Many situations within logistics are similar to situations in assembly and those solutions could be used for logistics too.

A simple scenario could be a logistics operator assigned to a picking station. The logistics operator is wearing smart glasses that shows the picking order, along with additional instructions. The operator pushes a cart with a specific fixture on it that has unique features depending on what is to be picked. While wearing the glasses, the operator can be guided to where the parts needed for the current picking order is located, with arrows pointing at the pallet. Following parts would be presented, but not as strongly to emphasise what part is the current one. To further ease finding the correct pallet, other pallets could be hidden using DR technology. When the operator has picked the part, the smart glasses verify that it is the correct part. This could be done by the glasses checking a unique marker on the part, or by checking that the correct fixture is used and then that the needed parts are put in the correct place on the fixture. A representation of this simple scenario is shown in Figure 12 below.

Forklift drivers could also use smart glasses to get information on what pallets are empty and needs changing, with priority assigned to them so that the driver always know what to do next.
6.2.3 Research and development

VR has been successfully used at Volkswagen to quicken the workflow for their styling departments. Similar tools would be useful for Scania’s stylists to decrease the lead time from creating a sketch to seeing it in 3D.

For any design engineer to be able to visualize their part or product in its environment would be a great asset. The design engineer could then easily fit the part or product into it a larger assembly and study tolerance chains, gaps or perform collision analysis.

It would also be beneficial to study the whole product in different stages of the refinement or lifecycle. By stepping through the whole process, the design engineer could together with experts from the different departments, easily verify that the new part or product suits all departments, from production and logistics, to marketing and aftermarket services.

Specific use cases suggested by one of the interviewees are for example verification of models for cast iron parts in VR. This would bring better scale and better visibility, therefore better ensuring that the cast iron parts would not get quality defects. (Bonde, 2018)

Another use case would be by combining an AR tool with a thermal camera, thereby making a tool for finding failing. If a running mechanical component gets hotter than it should, something is amiss. It could be because of failing bearings, too little or too much lubricant, joints that are too tight or too loose, or other problems. By combining a thermal camera that can display where the heat is dissipated, a normal camera to find the relative position on the component and adding an AR layer that puts geometries on top of the picture, a mechanic could see which part is likely to be failing. (Bonde, 2018)
Renovation/repair of central gears for rear axles. External suppliers are renovating/repairing central gears for rear axles, when the central gear is not functioning properly, but is not in such bad state that it is scrapped. The suppliers disassemble the central gear, clean and repair all parts and order new where needed, before the central gear is reassembled again. In order to verify which parts are in working condition or not, some AR application could be used. This could be connected to Scania’s service tool MULTI. The information in MULTI could present additional information on the part, such as if it is always to be replaced by a new part, or what areas on it that is critical to be in working condition, or other criteria for determining if the part is ok or not. (Bonde, 2018)

6.2.4 Purchasing
Overall, use cases within purchasing are likely not unique, but are rather reuses of others. A purchaser would benefit from showing a supplier what the factories look like, to make it easier to understand how the new part fits in to production. Likewise, it would be useful to show the parts in their respective contexts on the product. For these cases, VR would be useful.

By using a 2D drawing printed on paper as a marker, an AR app could then show a 3D model of the part or product that the drawing depicts. The user could then be able to see exactly how the part looks, and possibly also additional information like where the part is located on the product, and meta data such as dimensions and tolerances.

6.2.5 Marketing
Marketing events could benefit from using both AR and especially VR. With AR the attendee could see a truck with meta data attached to it, meaning that they could walk around it and get information about its performance, pricing, options etc. Using VR, however, would be even more beneficial. Here, the attendee could get a specific product placed in any type of environment. These environments could be a landscape of where the truck would be used or how it would look in different lighting. It is even possible for the attendee to test drive a truck to get a feeling for how different trucks look.

VR has another interesting aspect, as it could be setup to cater a specific audience one day and another the next, or even change per individual who uses it. This could prove a powerful tool not only to sell more products, but for attracting new employees to Scania. A recruiter could show the products, factories, workshops, or even connect to live 360-degree video feed to show a visitor around or interact with other Scania personnel on-site.

6.2.6 Sales
Presenting a customer with the ability to see their truck is a powerful sales tool. As Scania’s modular system enables so many variants of truck, it is not possible to have physical representations of all combinations. However, using VR this is no longer an issue, as it would be possible to display the customer’s configuration and visualize it. The sales person also has the added possibility of showing options that the customer was not aware of or had not planned on selecting, thus increasing the chance of added sales. Similarly, AR could be used to visualize options on a physical truck, thereby giving the customer a better understanding on how different alternatives look.

VR could also be used for test driving and placing the product in different environments, similar to how marketing could use it, increasing the customer experience.
6.2.7 Aftermarket

Many of the aftermarket applications and uses for AR and VR are similar to uses in production and logistics. A service workshop could use smart glasses to guide the mechanic to instructions on how to disassemble, service and reassemble a part. As workshops are not tacted like assembly lines, the information could be more detailed step-by-step instructions with both text, sound, and moving imagery to describe the process and what manoeuvres and tools to uses where. Similar to factory layout planning, tools for planning workshops could be used.

6.3 Gap analysis

Currently, the only supported formats that 3D CAD data is available in to Scania’s employees are native Catia, 3DXML, lightweight and Digital garage. None of these formats suit the needs for even the most common VR environments, where .fbx is used. Therefore, a manual operation to lighten and convert the Catia files to a useable format always has to be performed. Such a process is time consuming and is likely only for a one-time use. This is because Scania’s CAD data is updated daily, and a breakdown of a product one day might look different the next. As such, manual handling of CAD data is often obsolete or inaccurate from day to day, especially CAD data that is a part of a large product development project.

The Digital garage format is mostly a manual process. It therefore suffers from the aforementioned drawbacks of not being dynamically updated when changes occur, but instead is a static representation of how the product or breakdown was configured and modelled at that point in time. The lightweight format is created automatically in a nightly batch, and does therefore not have these issues with being locked to a fixed version of a product or breakdown.

While the automatically created lightweight format might be of use to more groups of employees than the targeted group that had the specific need that initiated the creation of the lightweight format, this has not yet been established. The lightweight format is still in its inception phase, and the target group is still evaluating its capabilities. No other groups have as of yet been asked to do the same, whereas the other possible use cases for the format remains unknown.

Similarly, while some stakeholders and use cases have been identified in this project, much is still unknown in regard to what VR and AR users at Scania need. While it can be said that all interviewed VR users need Scania’s product 3D data available in other formats than the native Catia format, it is not possible to solve all users’ needs with a single format or setup. Many could use .fbx files, but there are still several variables to take into account that makes the information in the file differ depending on the use case.
7 Conclusions and discussion

One of the earliest conclusions drawn in this project was that this subject is so hot and
development is so rapid that it is very hard to stay current. The information in this report is still
valid at the point where it is finished, but it is not the most up to date information available. This
is specifically true for the survey of Scania, as a lot of new information has been collected during
the finalization of the project. But due to constraints in time and the scope of the project, it was
not possible to take all of it into account, lest the project would never finish.

7.1 General

The field of virtual and augmented reality is quickly evolving. As technology gets cheaper,
computer equipment faster and more powerful and more research is put into finding new areas
to explore and new ways to solve problems, the field is advancing at a quick pace. Today, realistic
virtual reality is available to an affordable price to consumers, while augmented reality is readily
available in some form in any smart phone. While this is exciting and interesting in both a
consumer and industrial perspective, it is from an academic perspective harder to enjoy.

Many of the studies and research that have been performed regarding users and use-cases are
done in the last five or ten years, which would likely be considered recent in many other fields of
research. But the field of virtual and augmented reality has changed so much over the last five
years that much of this research is outdated. While research into how to produce realistic virtual
worlds and methods for augmenting a user’s daily work is still of interest, technical solutions on
how to implement them may very well be useless as current technology has surpassed them.

Thus, it has been hard to find relevant and current research in this field. Much of the cited
sources may suggest technology or methods that were not able to implement at that point, but
has likely been developed since and could be in use by several companies. Because of this it is
important to regard this thesis more of a source of inspiration as to what can be done at Scania
and elsewhere, utilising methods and technology for virtual and augmented realities, rather than a
specific guide.

Augmented reality and virtual reality are both very useful technologies with strengths in different
areas. Where a user has need for additional instructions or information, AR is the clear way to go.
Not only because almost any sort of information can be presented, the situations where AR can
be used are many. But when limits are to be broken, VR is unprecedented as a technology and as
a tool. While the user is physically bound to the real world, the virtual world can provide an
experience and environment that does not have these boundaries. Users can be presented with
information of any kind and in any form imaginable, where the user’s mind is the only hindrance.

Both VR and AR are deeply connected to visuals and the user observing the virtual environment
or information. Providing users with the possibility to present information to themselves and
others in completely new ways is the essential functionality of them both. To use them for purely
visualization situations is surely a good way of capturing the observing user’s eye and interest, but
using VR and AR to convey a message, bridging gaps in knowledge and enabling making well-
 founded decisions is definitely their key purpose.

As the number of applications for virtual reality and augmented reality is evidently great, it is only
a matter of deciding where to start using these technologies at Scania, not if. In regard to when to
implement VR and AR, the answer is not as clear. As many of the use cases presented in the
report have practical and working applications, many of them are not refined enough to be put
into daily use. Many of the presented use cases were performed in laboratory settings or test environment, and not in an industrial environment. However, since the development in this field is so rapid, it is likely that many of the use cases have been turned into industrial-grade solutions ready for implementation. It is therefore a case to determine if Scania want to be an early adopter of new technologies with high costs, risks of failure and unforeseen problems, but potential for gaining technological advances, or if they want to wait and reduce risks and costs, but also the advantages the early adopter gets.

Another aspect to regard in the presented flowchart is the matter of innovation and pushing the limits. While an alternative solution may be sufficient to solve a problem and suit the situation, it is not always clear from the beginning where all routes will lead. By instead using AR or VR in a situation like this, it is not unlikely that new and unforeseen possibilities arise.

As virtual reality equipment is cumbersome, expensive and often requires some training or experience to get the best possible experience, it is not unreasonable to think that this will keep virtual reality from becoming a tool in every person’s home or a common product for every company. Conversely, as augmented reality can be achieved with any smart phone that almost everyone today is already equipped with, it is not unlikely that augmented reality will be the technology that catches on with the masses.

An important factor to take into account is the social aspect of using VR and AR. Equipment with cameras filming the wearer’s surroundings are not always accepted by people around the user. With laws like GDPR regulating how personal information is allowed to be recorded and stored, it is of utmost importance to understand how VR and AR that records the physical environment is affected by such laws and what impact it has on work in offices and factories. The user experiment showed that some people were afraid of being teased or touched by bystanders. As some observations were made of bystanders having this behavior in an office setting, it is not unreasonable to think that it could be a problem if VR equipment got a widespread use at Scania. Not only should rules regarding how to behave in a VR setting be set up, but also rules for how others around the VR user should behave. Cyber bullying is an existing problem already, and it would be erroneous to believe that VR settings would be excluded. Harassment in a virtual world is exactly the same as harassment in the physical world, and as such the same rules and implications for breaking these should apply.

Other suggestions the digital images team put forth was to require that design engineers have to assign what surfaces are A-surfaces and B-surfaces respectively, as this would remove a lot of work and guessing from others who use the model. Another suggestion was that the models have to pass through a “model check” before being uploaded to GEO. This would ensure that the models fulfil certain demands and keep a minimum level of quality. The third suggestion is that the design engineer specifies both the material of the solids and the surfaces, as the surface material is not necessarily the same material as the solid. One example of this is the surface material of a cab body part, which is a lacquer, while the solid material is sheet metal. (Sahlin, et al., 2018)

7.2 Research and development

The literature speaks little of specific applications for AR and VR in research and development. This does not mean that there are no areas that could be improved using these technologies, however. One of the interviewees described that presenting and spreading information is one of the biggest issues within his field. It is not hard to imagine that a designer would show their newly designed part for concerned parties, independent of who that might be, in a VR setting.
Creating a multi-user environment where a Scania part or product is in focus would increase understanding of it by providing possibilities to have a life-like perspective on it, which would otherwise be impossible to do digitally, and physical parts would be required. Such a tool would help bridging the departmental silos and improve communication and let everyone get a better understanding of the product and how it would look in different environments at Scania, no matter if it is within R&D, production, marketing, purchasing, aftermarket or other.

7.3 Production

7.3.1 DTOA – Rear axle assembly line
There has been a lot of research into how especially AR can be used in production, and the potential implementations on the rear axle assembly line are several. Smart glasses that guide the user in the assembly process, either by providing the assembly operator with step-by-step instructions or verifying that the correct part has been picked, definitively have a use and would likely help the assembly operators to maintain standard procedure and assure quality.

But the important question here is not necessarily if AR or VR tools could be implemented in production, but if it would be beneficial for the process as a whole. The assembly process on the rear axle assembly line is streamlined and tact times are so short that only a few seconds could possibly be gained before physical restraints are the limit. Because of this, AR tools are not likely the big help they could be, as the process is already very efficient. It is likely so that smart glasses for example would not help assembly operators that much more than current tools already do, for instance pick-to-light systems that guide the user to pick the correct part. In a best-case scenario, the assembly operator would gain a second or two, but this short time is hard to use for something that could be translated into added value for the customer, thus making the time saved a waste.

7.3.2 DTOBM – Axle paint shop
As all the programming of the painting robots is done manually today, any sort of offline programming tool would be beneficial. This would allow the programmers work more efficiently and in parallel. A VR tool for programming would increase this even further. Life-size representation of the new product is helpful for understanding how to optimize the program and avoid collisions. It is reasonable to think that a programmer then would be able to do the programming immediately after the product design has been decided. As such, the lead time of a development project could at least be shortened by the 120 hours needed for a full new robot program. It is not difficult to imagine other parts of Scania where robot programming is currently done physically at the end of the development process, and that these would gain equally from an offline VR programming application.

7.3.3 DTL – Logistics
Part weights and centre of gravity is not only useful to properly design transport yokes and transport racks for DT. It is probably even more useful to have in virtual reality simulations, where physics are enabled. Then, it would be possible to perform actual test assemblies where the parts behave as expected when they are mounted. Lifting tools, equipment of other sorts, interactions with other parts and manual lifting could be evaluated using some sort of software, making it possible to verify the assemblability of a part very early in the development process.

While these examples (pick-to-voice and SMART factory picking lab) can be considered to be AR solutions, they are not clever. The solutions use a predefined list as input, instead of what it detects the material handler to have done. It is bound to the pre-set conditions of the system and
the material handlers input to work, while a cleverer system would detect what the material handler is doing and react upon that. It should also plan the route and optimise it using the material handler’s position and current task, not on manual input. Another drawback of using the glove as an input or confirmation tool for the AR system is that the material handler is required to let go of the item they are holding. As soon as a person releases their grip of an item, the ergonomics are deteriorating. This could pose a problem if the item is close to the weight limit of what a person is allowed to lift, according to Scania’s Ergonomics Standard. This would, however, not be a problem if the AR solutions were smarter and could verify the work themselves.

As the logistics development group has none of their digital resources in formats that could be used by any 3D software, as all layouts are in 2D and shelves, racks, boxes and pallets are planned and visualised using Excel, it would be a big job to transfer everything to a 3D environment. It would benefit from using a standard library of items, such as shelves, racks, boxes and pallets, but the main workload would still be to transfer current 2D layouts to a 3D layout.

7.3.4 Projects and production engineering

Large scale projects, such as factory planning and investment projects for new machines and equipment, have lots to gain by an iterative process where layouts are verified in virtual reality. But this requires that the current physical and virtual layouts are identical, or the project plans the new layout according to false information, and this could prove devastating in the end when the new equipment cannot be installed. This puts additional pressure on the production engineers and logistics engineers to keep the virtual layouts updated as soon as a change occurs, and will therefore be a risk and an added task to perform if these technologies are to be of use. The biggest challenge is to get everyone working with the same layout and having it show how it evolves over time. All details have to be available, all changes have to be planned, recorded and available to all involved parties, or this initiative will fail and cause problems for future projects. But if these are handled, factory planning in virtual reality is indeed a powerful tool.

7.4 Other departments

While there are other departments within Scania apart from Production and logistics and Research and development, their specific needs are likely not too different than what the two biggest ones would use. There are obvious benefits in sales personnel being able to show parts in their environments on the trucks and buses, while the purchasing department would have a need for this and also being able to show how the part is being assembled at Scania. Planning service workshops and having guidance in repair and maintenance tasks is a great step forward for the aftermarket. However, these needs alone are likely not strong enough to be beneficial to Scania if met, or even push the internal boundaries. Rather, it is a nice addition to have when the infrastructure is already in place by P&L and R&D.

One department sticks out from the others though, namely marketing. The current job market is very much in the favour for the employee, not the employing company. It is therefore critical to get new people working, and to find new ways to attract these people. One way would be to have an exciting booth at job fairs or other recruiting events. Showing Scania’s diverse job opportunities, interesting departments and being able to be on-site virtually, would indeed be an innovative way of sticking out, and one that Scania needs.
8 Future work and suggestions

The gap analysis shows that there is indeed a gap between the 3D data produced in Catia and what many users of the data actually need. It is therefore of great importance to continue the investigation into this matter from where this project leaves it. A pre-study should be carried out with the aim of interviewing all known stakeholders for what their product 3D data needs are. Additionally, currently unknown stakeholders should also be found and asked the same questions. From this, a single use case should be selected. This use case is then the foundation for a test project with the goal of automating the whole process of lightening and converting the native Catia 3D models into what the stakeholder needs and wants.

One way of finding new stakeholders and their interests is to put together an improvement group for the area of VR and AR. Such groups exist throughout Scania already, so the concept is not new. An improvement group for VR and AR should gather stakeholders cross-functionally from Scania to a forum where common interests is central. This improvement group should discuss common topics, such as how to overcome hindrances for future expansion of VR and AR use at Scania, support current and new users of VR and AR with experience, market the group and the field of VR and AR to Scania at large, and make decisions for standardization of VR and AR equipment, tools and platforms.

Regarding standardization of tools it is of great importance to make a decision of what game engine to use, if any. Since most of the interviewed stakeholders at Scania are using Unity, or know of others that are using it, for their own VR development purposes, and Volkswagen group has decided to use Unity, it seems logical for Scania to go for Unity as well. Especially since it seems to be the general consensus among the interviewees that Unity is easier, if somewhat less powerful graphically, and the supporting community outside of Scania is much greater than for Unreal Engine. However, if Unity does not serve every stakeholders’ purposes, it is of utmost importance to understand their needs before deciding what game engine to support and what to reject.

While several of the interviewees are already working with VR, and many of the others know that someone else is using VR at Scania, some were unaware of the current initiatives at Scania. This is likely to be the case for most employees at Scania. Therefore, it is of high importance to present these initiatives and that VR and AR is available for use at Scania, to encourage new users to enter into the field. As many employees at Scania is likely to not have worked or even used VR or AR before, a way of demonstrating what possibilities VR and AR are capable of is needed. A lab similar to the virtual engineering lab that Volkswagen has would serve this purpose. Such a lab could demonstrate and showcase new technology overall, and try out new concepts and ways of working at Scania and within R&D especially.

The presented chapter “Road map” should be taken into consideration when Scania is deciding on how to move forward. This chapter and the presented activities, along with the paragraphs above should all be part of the road map. But in addition, Scania should formulate a broader vision for how to proceed in working with VR and AR, that acts as the foundation for the road map upon goals and activities are mapped. In this sense, it is important to support innovation via virtual engineering and labs, but also to work towards long-term industrial out-of-the-box solutions that can be maintained over time.
8.1 Road map

8.1.1 Within the next year
Establish an improvement group for employees using VR/AR in their work. This group needs to get mandate for decision making to be able to find and establish best practices, what tools to use and how to standardise work and interfaces.

Establish a lab working similarly to the Virtual Engineering lab in Wolfsburg. The purpose for this lab should be to further investigate and test use cases where VR and AR could be used and implemented into daily work.

Standardise what equipment is available at Scania. Recommended is to use HTC Vive Pro when it is available. To power this, a special version of the AWS should be available with prosumer graphics cards instead of very expensive professional cards.

Find a single use case of a downstream application that should be supported by an automated process that eliminates or reduce the need for manual preparation work on part and product models before they can be used.

8.1.2 Within the next five years
Game engines will only be increasing in strength and what possibilities that comes with that. Therefore, it is important for Scania to choose what game engine to use and support. Having a preferred game engine will enable users at Scania to better work together by standardising interfaces, sharing models and other work, while making it possible to prepare CAD data for the specific purposes.

In order to fully be able to use VR and AR it has to have access to CAD data in other formats than is readily available at Scania today. Therefore, it has to be prepared for whatever situation it is needed in. Because these needs differ depending on several factors, such as use case, displays and computing power, a larger investigation is required to find out what is needed.

8.1.3 Within the next ten years
The use cases for VR and AR are many, and while several of them are not ready for implementation yet, this number will decrease over time. On the other hand, as the market for VR and AR is so quickly expanding into new territory it is hard to predict what will happen.
References


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Hanson, L., 2018. [Interview] (10 April 2018).


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[Accessed 02 June 2018].

Available at: https://xmreality.com/how-it-works/
[Accessed 02 June 2018].
B. Simulator Sickness Questionnaire

No__________________________  Date__________________________

SIMULATOR SICKNESS QUESTIONNAIRE
Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions: Circle how much each symptom below is affecting you right now.

1. General discomfort
   None    Slight    Moderate    Severe

2. Fatigue
   None    Slight    Moderate    Severe

3. Headache
   None    Slight    Moderate    Severe

4. Eye strain
   None    Slight    Moderate    Severe

5. Difficulty focusing
   None    Slight    Moderate    Severe

6. Salivation increasing
   None    Slight    Moderate    Severe

7. Sweating
   None    Slight    Moderate    Severe

8. Nausea
   None    Slight    Moderate    Severe

9. Difficulty concentrating
   None    Slight    Moderate    Severe

10. « Fullness of the Head »
    None    Slight    Moderate    Severe

11. Blurred vision
    None    Slight    Moderate    Severe

12. Dizziness with eyes open
    None    Slight    Moderate    Severe

13. Dizziness with eyes closed
    None    Slight    Moderate    Severe

14. *Vertigo
    None    Slight    Moderate    Severe

15. **Stomach awareness
    None    Slight    Moderate    Severe

16. Burping
    None    Slight    Moderate    Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

C. General user experience form

Survey ID:

Please circle the number corresponding to your answer. 0 is none, 1 is little/weak/bad, 5 is much/strong/good.

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you used VR before (more than 10 minutes)?</td>
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<td></td>
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<tr>
<td>What was your overall impression of VR before the session?</td>
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<td>1</td>
</tr>
<tr>
<td>What was your overall impression of VR after the session?</td>
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<td>1</td>
</tr>
<tr>
<td>How real did the simulation feel?</td>
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<td>1</td>
</tr>
<tr>
<td>How intuitive was the simulation?</td>
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<td>1</td>
</tr>
<tr>
<td>In general, how well did you feel after the session?</td>
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<td>1</td>
</tr>
<tr>
<td>Were you afraid during the simulation?</td>
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<td>1</td>
</tr>
<tr>
<td>- Tripping</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>- Colliding</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>- Teased by other person</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>- Touched by other person</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>How was the picture sharpness?</td>
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</tr>
<tr>
<td>Do you use corrective glasses or contact lenses?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>- Did you wear corrective glasses or contact lenses when using the headset?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>How comfortable was the headset?</td>
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<tr>
<td>How adjustable was the headset to make it comfortable?</td>
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### D. Observation form

**Survey ID:**

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<th>Score 4</th>
<th>Score 5</th>
<th>Description</th>
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<td>Careful</td>
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<tr>
<td>Rash</td>
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<td></td>
<td></td>
<td></td>
<td>Cautious</td>
</tr>
<tr>
<td>Aggressive</td>
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<td></td>
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<tr>
<td>Excited</td>
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<td></td>
<td>Calm</td>
</tr>
<tr>
<td>Uncomfortable (in situation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calm</td>
</tr>
<tr>
<td>Uncomfortable (with simulation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calm</td>
</tr>
<tr>
<td>Needs help (with simulation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No help – interacts intuitively</td>
</tr>
<tr>
<td>Unnatural movement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moves naturally</td>
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### E. Results from Simulator Sickness Questionnaire

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### F. Results from General user experience form

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<th>What was your overall impression of VR before the session?</th>
<th>What was your overall impression of VR after the session?</th>
<th>How real did the simulation feel?</th>
<th>In general, how well did you feel after the session?</th>
<th>Were you afraid during the simulation?</th>
<th>- Tripping</th>
<th>- Colliding</th>
<th>- Teased by other person</th>
<th>- Teurred by other person</th>
<th>How was the picture sharpness?</th>
<th>Do you use corrective glasses or contact lenses?</th>
<th>- Did you wear corrective glasses or contact lenses when using the headset?</th>
<th>How comfortable was the headset?</th>
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