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Is Augmented Reality the future of business?

A qualitative study on factors affecting the potential for mass adoption of augmented reality in business processes.

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Abstract

Augmented Reality (AR) is one of the emerging technologies of the Fourth Industrial Revolution that might bring radical shifts to the way we live and interact with the world around us. This thesis examines the benefits and use cases of AR in business processes. Furthermore, it examines the limitations and barriers that can explain why more companies are not committing to the technology.

The aim of the thesis is to determine if AR belongs in the future of business, and if so, when there will be mass adoption. To do so, we interviewed 10 individuals with experience and expertise in AR. Using thematic analysis, we divided the findings into three different time periods, *yesterday, today,* and *future*. Limitations and barriers were further divided into four categories: *hardware, UX and software, culture and society,* and *company*.

Our findings reveal several benefits to AR, for example improved efficiency, accelerating training and reducing costs. More importantly, AR is set to drastically change how we see and interact with our surroundings. It has the potential to become an integral part of our daily lives. However, findings highlight several limitations and barriers that must be overcome for AR to reach mass adoption. Most prominently, cumbersome hardware, and the need for acceptance and a normalization of AR in both companies and society. Nevertheless, we conclude that mass adoption of AR is likely to happen in the next 10 years. Consequently, the thesis imply that companies should prepare themselves proactively for an AR revolution, so that once the limitations and barriers are softened, companies are able to keep pace with the technological advancements and thrive in the years to come.

Keywords – Augmented reality, Industry 4.0, Digitalization, Future business processes

Contents

1. Introduction

1.1 Background

Digitalization in the 21st century has imposed numerous challenges to conducting business. The working environment is swiftly shifting and keeping pace with the markets can be difficult. Unforgiving mistakes are not only made based on what a business did, but now more than ever what a business did not do. In the worst case, businesses risk losing it all if they do not invest in emerging technologies before it is too late.

Along with staying afloat in a fast-paced market, businesses also need to find optimal solutions that lead to positive business outcomes. Otherwise, businesses risk losing competitive power to more efficient companies. To stay competitive, many companies are investing heavily in finding better ways of working. Lately, there has been a lot of attention surrounding technologies of what is often referred to as the *Fourth Industrial Revolution,* also known as *industry 4.0*. As described by IBM (2020):

> Industry 4.0 is revolutionizing the way companies manufacture, improve, and distribute their products. Manufacturers are integrating new technologies, including Internet of Things (IoT), cloud computing and analytics, and AI and machine learning into their production facilities and throughout their operations.

Under the umbrella of industry 4.0 lies the phenomenon of *Augmented Reality* (AR). According to GlobalData's Emerging technology Sentiment Analysis, AR was considered the most disruptive emerging technology in Q2 2021 (GlobalData Thematic Research, 2021). To reduce the threat of losing competitiveness, companies should thus investigate such disruptive technologies. This thesis focuses on exploring AR and aims to shed light on whether it is an important factor in future business.

1.2 Relevance and importance

Augmented Reality is often discussed as a technology that shows potential in several fields. Some examples are Michael E Porter and Heppelmann (2017), who found that AR can create business value in the value chain, manufacturing, logistics and sales. Fraga-Lamas et al. (2018) examined AR applications in the shipyard industry, highlighting several additional categories where value can be added. Furthermore, Pratt et al. (2018) discusses how surgeons can use the technology to reduce the anesthetic time and morbidity associated with surgery, while Fink (2019) explains how Boeing connects technicians and experts for more efficient airplane assembly. Nonetheless, businesses are seemingly reluctant to implement AR, and as explained in an article by BCG in 2018 (Hutchinson & Aré, 2018), many of the business leaders they spoke with daily were frustrated by the lack of speed with which their companies were embracing new technologies.

This thesis builds upon the existing literature in the field by highlighting the benefits of AR, along with limitations and barriers of the technology. By discussing if and when the time is right for mass adoption, the thesis can give businesses, policymakers, educators, and researchers a better decision basis when considering investing resources in AR.

1.3 Research questions

Given the positive talk about AR, why then, is the technology not utilized to a greater extent by businesses? Some would argue that the influence of the technology is overestimated, such as Dmitry Bagrov, the managing director of global technology consultancy, did in an interview with Verdict (Daniel, 2018). This is contrary to Shelly Palmer, chief executive officer of strategic advisory firm The Palmer Group, who predicts it to be "the future of the universe" (Gates, 2018).

The gap between this powerful and potentially disruptive technology, and the lack of mass adoption in various business processes raises the question:

Is augmented reality the future of business?

To answer this, three research questions have emerged:

I: What are the benefits of implementing AR technology in business processes?

II: What limitations and barriers prevent mass adoption of AR, and which factors need to be in place for AR to reach mass adoption in business processes?

III: When is the right time for mass adoption of AR in business processes?

By *business process*, we are referring to structured activities or tasks that are required to produce or offer a product or a service. This can for example be assembly and maintenance of a machine or using a machine or a tool to produce goods.

By *mass adoption* of AR, we are referring to a time in which the technology is commonly used. Smartphones are an example of a technology that is mass adopted.

The first underlying question has the purpose of mapping out the case *for* AR. Firstly, by looking at how it fundamentally changes how we interact with the world around us, and what that means in terms of human behavior and benefits that may be a result of it. Secondly, by looking at how companies are and can utilize AR to improve various aspects of their businesses, such as efficiency, costs, or customer relations.

The second underlying question aims to map out the case *against* AR. Firstly, by looking at technical limitations. Secondly, by looking at broader challenges and barriers companies face when implementing AR. In order to make a qualified prediction of the future of AR, it will also be discussed whether these limitations and barriers can be overcome in the future, and if so, how?

This leads to the third question, which aims to determine the maturity of the technology. Is it too early, too late, or the right time to invest and prioritize AR for companies? Alternatively, if no time is the right time. In doing so, we not only determine if AR belongs in the future of business but provide an estimation for when a clear answer to this question might present itself, and what factors need to be in place for that to happen.

1.4 Scope

In our initial search for a finalized research question, discussions with AR experts gave us the impression that the potential for AR is most significant in industrial settings, such as manufacturing. This thesis will therefore focus on the use of AR in industrial settings, as opposed to for example entertainment or retail stores. Nonetheless, examples from other fields are also utilized to illustrate essential elements of AR and to add valuable points to the discussion. The study is done with a qualitative approach, and primary data is gathered from people with expert knowledge and experience with AR.

To fully understand AR and the maturity of the technology, it may prove beneficial to look at it with a holistic view. The evolution of AR must be understood to be able to evaluate the research questions thoroughly. Therefore, the findings of this thesis are divided into three different sections, hereunder the *past*, *today*, and the *future*.

1.5 Structure

The thesis begins by introducing augmented reality, its history, and its features. This is all categorized in chapter two, the literature review section of the thesis. Next, the research design is discussed in chapter three. Here, we elaborate on our approach to the research questions. Chapter four addresses our findings and the discussion surrounding those. Furthermore, chapter four includes a section discussing the implications for businesses and potential future research as well as limitations of the research. Finally, a conclusion to the thesis is given.

2. Literature review

2.1 What is Augmented Reality?

Augmented Reality (AR) is when digital content is overlaid onto the physical world. Data and analytics are transformed into various forms of visual elements, sound, or other sensory stimuli, that are then added to the user's physical surroundings (Schwab & Davis, 2018). The digital content responds in real time to changes in the user's environment, either as a response to the actions and movements of the user, or in relation to objects in the physical world (The Interaction Design Foundation, n.d.). For example, visuals displaying the changing temperature of a machine, or GPS overlays helping the user find directions from street views.

Accomplishing this, however, requires a lot of data and processing power. Hence, technological development being a crucial factor in bringing AR beyond a concept of science fiction and isolated applications, to a point of considerable impact for businesses. To what extent present technology is unleashing the full potential of AR is still debatable. Nevertheless, we are currently seeing a growth in use cases for AR, especially with the rise of data collection.

Michael E. Porter and James E. Heppelmann highlights this fact by stating that there is a fundamental disconnect between the wealth of digital data available to us and the physical world in which we apply it (Michael E Porter & Heppelmann, 2017). There is significant value in the volume of data and analytics we now possess, and AR can play an important role in helping us make sense of, and utilize, that data. They further state that while reality is three dimensional, the rich data we now have to inform our decisions and actions remains trapped on two-dimensional pages and screens. Transforming information that traditionally is presented in a two-dimensional format, to the three-dimensional, is a core attribute of AR (Michael E Porter & Heppelmann, 2017).

For this virtual information to be viewed in combination with the physical world, a form of display is required. Display technologies applicable to AR can be divided into two types: video mixed and optical see-through displays (Fraga-Lamas et al., 2018).

A video-mixed display merges virtual and real information onto one display. Today, this typically comes in the form of a hand-held display, such as a smartphone or tablet. Optical see-through displays on the other hand, superimpose the virtual information onto the user's field of view with an optical projection system. Today, this typically comes in the form of head-mounted displays included in devices such as smart glasses and smart helmets, which allow users to see the entire environment that surrounds them.

Hardware with hand-held displays is currently the most accessible form of display. However, head-mounted displays have become more obtainable in recent years with the emergence and development of such hardware. Head-mounted displays have the added benefit of further improving the field of view, allowing the user to interact with and internalize information, without taking the attention away from the real world.

This is also a defining distinction between AR and *virtual reality* (VR), another form of technology that is often discussed alongside AR. While AR adds digital content to the real world, VR immerses the user in a fully digital world. VR is a multisensorial, three-dimensional, 360-degree computer simulated environment, that the user can immerse themselves in and interact with (Schwab & Davis, 2018). Furthermore, bridging the gap between AR and VR, is mixed reality (MR). MR is an extension of AR that also includes virtual elements. On a spectrum from real world to fully digital, MR can be found somewhere in the middle, between AR and VR, thus including some elements of both. This is illustrated in figure 1.

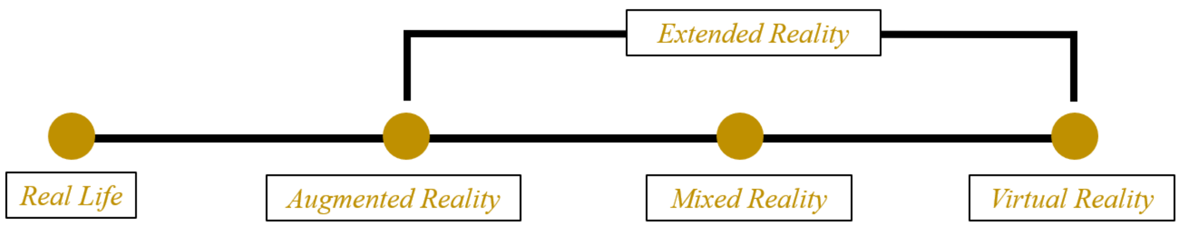

Figure 1: Spectrum of reality

To give examples of the extended reality depicted above, imagine the following scenarios. With VR, the user can step into a virtual replica of a kitchen, with a digital stove, digital fruit, a digital fridge, giving an idea of how it looks without ever visiting a showroom. Now imagine being in a showroom of said kitchen. With mixed reality, the user could map out the room, creating a digital twin of it. The user is then able to put pictures on the wall or change the color of the refrigerator. This is possible because the virtual objects are now aware of information such as the room size. Lastly, with AR the user could look at the physical refrigerator and see virtual information displayed on top, informing about its temperature, power consumption, how full it is, how fresh the groceries are and a list of groceries inside.

It should be noted that there exists some confusion between AR and MR. There are many similarities between the two and as a result, the terms are often used interchangeably (The Interaction Design Foundation, n.d.). “Augmented reality” is the better-known term, which could explain why it is preferred. However, as we defined, it refers to digital content being overlaid onto the physical world. The digital content is merely *superimposed* on real-world views. In MR, as explained, the digital content can *interact* with the real world. For example, when anchored to a location it moves depending on the wearer’s perspective, to appear as if it stays in place. Certain examples and use cases used in this thesis can also be defined as mixed reality. However, to simplify, it will all be referred to as AR. With a solid understanding of what AR entails, it can also be valuable to consider the history of how we got to this point.

2.2 A brief history of Augmented Reality

Augmented Reality is known to have started as an idea all the way back in 1901, when Frank Baum wrote about the concept in his novel *The Master Key.* The story, which at the time was pure science fiction, was about a kid that was given a pair of spectacles. The spectacles would display letters on people’s foreheads based on the person’s character.

The first real example came during World War II by the British military, best known as Mark VIII Airborn Interception Radar Gunsighting project (Vaughan-Nichols, 2009). The project developed technology that would allow pilots to see radar information on their windshield, resulting in them knowing better which planes were friends and foes. This technology is often referred to as a *head-up display* and has in later years proven to be effective in driving performance by several researchers such as Liu (2003) and Sojourner & Antin (1990). The head up display is as of 2022 a common feature in new cars.

In 1968, Ivan Sutherland created the first *head-mounted display*. The objective of the invention was to surround the user with three-dimensional information. However, since the processing power at the time was limited, only simple wireframe drawings were possible (Sutherland, 1968). AR technology was still not widely used, and thus no well-known research was conducted on the overall business impact the technology could potentially cause. Nonetheless, the technology did continue to improve with several iterative inventions. In 1992, Tom Caudell and David Mizell proposed a head-mounted display for wiring instructions when working for Boeing (Caudell & Mizell, 1992). Not only did they coin the term *augmented reality,* but they also became known for being pioneers of using AR in industrial settings (Mealy, 2018).

Using AR in industrial settings soon caught the attention of researchers. For example, Baird and Barfield (1999) found in their experiments that a head-mounted display with AR were more effective instructional aids for assembly tasks than paper manuals or computer aided instructions.

The sparked interest of AR in industrial settings soon expanded to other areas of business. The gaming industry was one of them, which has arguably been an influential driver for the advancement of the technology. In 2000, the first AR game was created (Carmigniani et al., 2011). Video games were getting increasingly popular at the time, and in 2005, Adam Carstens and John Becks even predicted that video games would have a significant impact on the future workplace (Carstens & Beck, 2005).

In 2007, Apple released their first multi-touch screen mobile phone. Similarly, a range of products, applications and other technological innovations had been invented, allowing for new ways to interact on mobile devices. These innovations included the introduction of what is often referred to as Web 2.0, where sites and services allowed end-users to create content, thus encouraging social networking (O'Reilly, 2005). These innovative breakthroughs helped spark the accessibility of AR for both businesses and regular consumers. As stated by Schmalstieg et al. in the chapter "Augmented Reality 2.0" in the book *Virtual Realities*, the developments in mobile and web technologies allowed AR applications to be deployed on a global scale and used by hundreds of thousands of people at the same time (Schmalstieg et al., 2011).

A prime example of this occurred in 2016, when one of the most well-known and first global-scale applications utilizing AR-technology was introduced. The application, named *Pokémon GO,* was a mobile phone game that attracted tens of millions of users worldwide. Players would be able to see and capture virtual monsters (Pokémon's) augmented on to the real world, using their mobile phones. The game has had a noticeable impact in several fields. For example, Althoff et al. found the game to be beneficial for the health of the players by drastically increasing physical activity (2016). Gabbiadini et al. (2018) concluded with the same results, pointing to the fact that the players were more active because the game required so. Furthermore, not only is the game known to be beneficial on a user-level, but it has also inspired businesses to take part in AR. For example, businesses could pay Niantic, the company behind the game, to make the Pokémon's appear at their location, thus attracting traffic and potential customers (Chen, 2016).

The same year as Pokémon GO was introduced the first version of Microsoft's HoloLens was released. The HoloLens is a pair of spectacles, like the ones depicted in Frank Baum's *The Master Key.* With the emergence of big data and industry 4.0 in combination with inventions such as the HoloLens, many companies were now able to capitalize on the potential of AR. For example, production companies could now train their workers by giving them a tablet or an AR headset, pre-installed with instructions in the form of virtual arrows, text, sounds, and videos that stick to the machines in the factory. This limited the need for a senior worker to train a new worker, reducing training time and costs.

More examples of AR development followed suit. In 2017, Apple released their AR toolkit, ARKit. This was quickly followed by Google, who released ARCore in 2018. The potential of AR became increasingly recognized by big and established technology companies. Such toolkits also allowed for more development in the AR space, thus allowing for even more innovations and potential use cases. In late 2018/early 2019, 5th generation mobile network (5G) began rolling out, one of many technological developments further enabling AR. Due to factors such as testing and regulations however, it could not be rolled out instantaneously (Fisher, 2022).

While technological developments further enabled AR, other factors hindered it. An example of this was the Covid-19 pandemic. The economic impact the pandemic brought influenced investor's risk-willingness (HSBC Global Private Banking, n.d.), consequently, leading to reduced investments in the AR field (Justice & Fersht, 2020). However, with the pandemic passing and the recent shift of focus towards mixed reality solutions, such as Facebook changing to Meta (Isaac, 2021), or rumors about Amazon developing AR glasses (Peters, 2022), the anticipations and excitement surrounding the many features and use cases of AR were arguably brought back to the limelight.

2.3 Augmented Reality key features

From military troops being able to see realistic, animated, and reactive virtual targets during training (Brown, 2005), to mobile phone games where players can hunt virtual monsters displayed in the real world (Pokémon, 2015), it is fair to argue that the use cases for AR are vast. What they all have in common is that they utilize one or more of the key features of AR, which can be categorized into *visualize*, *instruct, and guide* and *interact*. These features will be explained in further detail, to get a better understanding of the capabilities of AR and how the technology can make an impact on business processes.

2.3.1 Visualize

Humans process information through senses at different rates, and vision is one of the senses that provides us with the most information. By *visualizing*, we are referring to the act of making a mental image of something. For example, a surgeon needs to make a mental image of what is beneath a patient's skin, thus he needs to *visualize* how the patient looks inside. With AR, more information can be *visually sensed*. With *visually sensed,* we are referring to the act of actually seeing something, not just mentally. This ability to not only mentally visualize but to actually see something makes AR especially powerful in situations where visualizing is important.

As Pratt et al. (2018) explains in *European Radiology Experimental*, surgeons were able to use AR technology in combination with CTA scans and Microsoft HoloLens to assist the accurate identification, dissection, and execution of vascular pedunculated flaps during reconstructive surgery. Surgeons were able to "look through" the skin of the patient, resulting in reduced anesthetic time and morbidity associated with surgery. Figure 2 shows the surgeon's point of view of a patient after a traffic accident in that particular study.

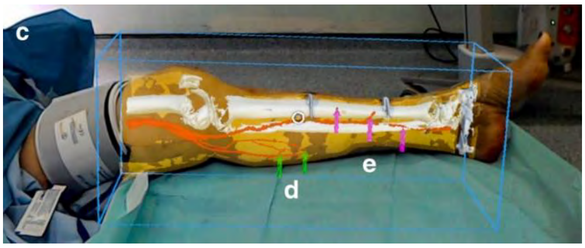

Figure 2: A surgeon's point of view. (Pratt et al., 2018)

This "X-ray vision" can be used in many other situations as well. For example, Bosch Rexroth, an engineering firm, used the technology to demonstrate the design and capabilities of its CytroPac power unit. Customers could use AR to visualize the unit's internal pump and cooling options without having to dismantle the whole system (Michael E Porter & Heppelmann, 2017). Another example is seen in the military, where pilots of F-15 fighter jets now possess the ability to see through the walls of the planes they are sitting in, making their field of view significantly larger (Moynihan, 2016). What the pilots before had to mentally visualize, they can now visually sense.

The feature of visualization is not only valuable as a form of x-ray, but also in a more regular sense of visualizing something in your surroundings. IKEA's AR app *IKEA Place* is a good example of this. It allows potential customers to visually sense how different furniture would look in their homes before deciding to buy (IKEA, 2017). Using AR in such a way also allows companies to display large machines and vehicles at sales fairs and other places where there is little room. Next, companies utilizing AR can also benefit from the feature *instruct and guide*.

2.3.2 Instruct and guide

When talking about instructing, we are referring to the act of *telling* someone what to do. In a manufacturing facility, it could mean telling a technician to assemble a machine. When talking about guiding, we are referring to the act of telling or showing someone *how* to do something. In a manufacturing facility, that could mean giving a technician a bolt and pointing at the hole where the bolt goes. With AR however, expert workers can remotely see and modify other more novice workers' field of view in real time, making instruction and guidance more accessible and more effective than before.

An obstacle many companies face is how to make training new personnel cost efficient. Often, senior workers would be given the responsibility of training new employees. This is costly for companies, as those seniors would have to shift their focus away from other important tasks. Some companies are battling this by, for example, offering online learning programs and courses. However, with the online environment being different from the real world, it is often not an ideal solution. Furthermore, many professions require the following of instructions and guidance from user manuals and checklists. AR's key feature of *instruct and guide* could be a far more engaging and efficient way of doing this.

Boeing is one of the companies that does just that. The company uses AR in combination with a head-mounted display to guide the installation of wiring harnesses' throughout aircrafts (Fink, 2019). Instead of constantly looking back and forth between a manual and the wiring harnesses, the instructions are augmented through the technicians' glasses. If the worker needs further guidance, they can turn their video stream on so that engineers or other technicians can look directly at their problem UpSkill (2016). The technician's point of view with the AR glasses is displayed in figure 3.

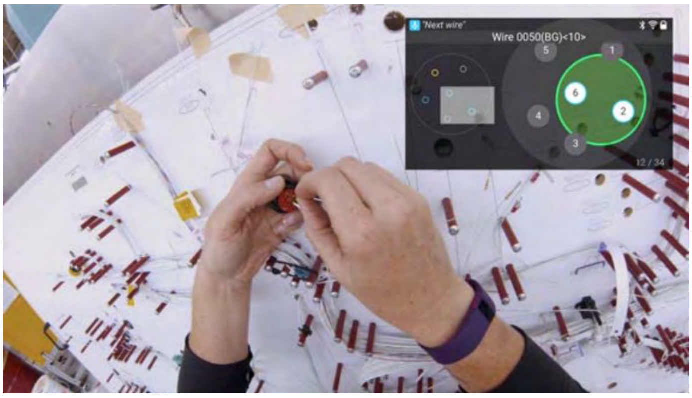

Figure 3: Boeing end-user's point of view (Upskill, 2016)

Depending on which AR solution the company is using, experts may even be able to modify the technician's view, by for example remotely drawing figures on the objects the technician is seeing. This way the expert can highlight and sketch important instructions that are easier seen than explained. Figure 4 shows an example of an expert (right) highlighting which valves a technician should modify (left). This way of communicating reduces the need for technicians and experts to travel. Furthermore, this way of communicating can be used to provide end-users quicker and more efficient installation guidance, troubleshooting and support. Heavy and complex objects may be fixed remotely, saving time and money.

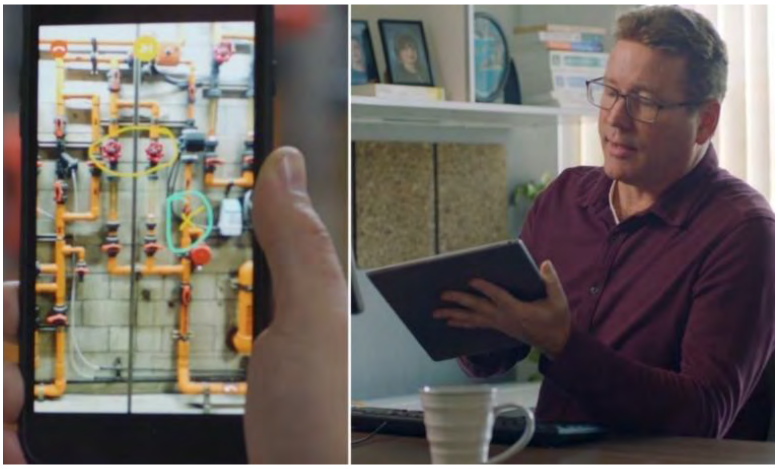

Figure 4: Vuforia Chalk (PTC, 2017)

Finally, using AR for instructing can be exemplified by the automotive industry, where the feature has gained increasing popularity. For example, companies such as Audi offer what they call a "head-up display." The display shows relevant, optional information such as speed, navigation arrows or indications from the assistance system while driving (MediaCenter, 2018), as shown in figure 5.


Figure 5: Head-up display (Audi, 2018)

These examples prove the usefulness and potential that AR can bring with its key feature *instruct and guide*. The last key feature of AR is *interact*.

2.3.3 Interact

A hundred years ago, a machine would be operated by pushing buttons and pulling levers. Nowadays, similar machines are often configured by touch panels or mobile apps. AR is another evolution, enabling humans to interact with machines in a whole new way. By augmenting virtual, and thus very customizable control panels directly on to a machine, an operator can configure the machine simply by using hand gestures and voice commands (Michael E Porter & Heppelmann, 2017). For example, a worker could wear a head-mounted display, stroll down the aisle of a factory, see each machine's performance parameters as he walks, and adjust each machine accordingly. All without ever physically touching a machine. Such interaction is not limited to machines; AR allows objects to be interactable even before it is physically created, with CAD models.

A Computer Aided Design (CAD) is in its simplest form a three-dimensional drawing. It is frequently used by a range of professions such as architects, game artists and engineers. AR allows such drawings to be added to the real world. This combination of 3D models and real life allows production companies to visualize and interact with new products in the early stages of the design process. As shown in figure 6, a


Figure 6: CAD and AR (Woohun & Jun, 2005)

designer visualizes the 3D CAD model of a cup before it is physically produced (Woohun & Jun, 2005). This allows the designer to get a feel of the size, color, and other features of the CAD model before producing it, potentially saving money by producing fewer physical prototypes.

Using CAD models is not limited to producing and designing new products. An example from the clothing industry is the smart mirror. With the smart mirror, potential customers can test out products virtually, simply by looking in a mirror that changes what they are wearing. The smart mirror can thus show customers more clothes in a shorter time, potentially amplifying the customer experience. Furthermore, the smart mirror reduces the need for the stores to keep inventory. Companies such as MemoMi and Saks Fifth Avenue are among those that are utilizing this (Daniel, 2018).

So far, we have defined what AR is, put it into a historical context, as well as highlighting its key features that may have impact on business processes. This has all been done with the aim of reaching an overarching understanding of AR. In doing so, the groundwork for analyzing findings and discussing the research questions has also been laid. The next chapter will present the research design of this thesis.

3. Research design

The research was structured as an exploratory study using qualitative data as our source of information. A thorough review of the academia done on the past, present and future of AR created the basis for discussion. It was then decided that facilitating interviews with people who had experience or expertise in AR could provide valuable insights, opinions, and predictions relevant to the research questions. Given the opinionated nature of our main research question, it was preferable to interview a heterogeneous set of people with diverse backgrounds, roles, and viewpoints relative to AR. This also meant an inductive approach would be followed, as our data analysis would be based primarily on these interviews.

3.1 Data collection

The data for this study was sourced from a combination of primary and secondary data. Primary data is data collected by us, the researchers. This is opposed to secondary data, which is the data that has already been collected. The combination of the two provided valuable information in different ways and complemented each other by triangulating the data. The main purpose of the secondary data was to develop a thorough understanding of AR, its past, present, and future, and was crucial for the overall discussion of the research questions. The secondary data derived from books, reports, academic research, articles, websites, publicly available information from company websites and personal sources. Furthermore, the secondary data played a vital role in the development of an interview guide for the gathering of primary data, which came in the form of semi-structured, individual interviews.

After extensive literature review and discussions with relevant industry contacts, we were left with a good understanding of what information was easily available and what was not. With the goal of providing additional insights to research already done and to answer the research questions at hand, it became clearer what data was needed from the interviews. While keeping the research questions in mind, we mapped out desired information and created an interview guide.

Firstly, we realized that we wanted the interviewees' perspectives on benefits, limitations, and barriers of implementing AR. It was also necessary that interviewees could provide insights on the value of AR from a business perspective. In addition, it was important that they could provide educated predictions and insights about the future of AR and suggest a possible timeframe for mass adoption. Given the aim of the thesis and the detailed information required from interviewees, it was considered preferable to have lengthy interviews with individuals that either had experience with AR or who had some level of expert knowledge on the topic. This was favored over having many short interviews or conducting a survey. The approach was also chosen due to the time and resource constraints of the thesis. 10 interviews of at least 30 minutes in length was considered a feasible goal that would provide sufficient data to answer the research questions.

Furthermore, to gain insights and perspectives that could help answer the three research questions posed, it was important that the questions provided enough opportunity for the interviewees to give a holistic view of the topic. In other words, allowing them to share their own insights and opinions, but also ask questions that could challenge their personal biases or agenda. The interviewees were individuals with personal experience and expertise on AR. A concern was therefore that they would be overly positive, given that they were already invested in AR, or would potentially benefit from putting AR in a good light. With that in mind, some questions were developed to try and counteract this. They were designed to challenge their view and to allow the interviewees to reflect on factors that could build a case against AR. Anonymity was also ensured at the beginning of every interview, to limit the fear of going against the interests of the company they worked for.

The flexibility to follow interesting, yet unplanned topics during the interview process (Saunders, 2016), made semi-structured interviews an appropriate technique for gathering the interviewees' perspectives. The interview guide provided the necessary, yet limited constraints needed for this approach, as it presented questions that were relevant for all interviewees.

Theory on how to develop and deliver these questions was considered to maximize the value and quality of the interviews. Robson (2002) listed several types of questions to avoid in interviews and were used as guidelines. For example, leading questions were avoided. Instead of asking “why are you optimistic about AR?” we asked, “how do you feel about AR?” Robson (2002) further pointed out that questions should avoid jargon unfamiliar to the target audience.

"AR" can for example be seen as such a word. Nevertheless, given the inherent knowledge our interviewees had about the technology, this was not seen as an issue.

A potential issue, however, was time. Although each interview was scheduled for a minimum of 30 minutes, the possibility of shortened interviews had to be considered. This could for example be due to interviewees having limited time available, or other technical and practical issues of conducting the interviews online. Therefore, a small selection of questions was chosen as core questions. These questions would be prioritized and asked to every interviewee. This was to ensure adequate perspectives on essential elements of our research questions. The other questions would be discussed once the core questions were answered. Questions deemed more relevant to the particular interviewee, their position and industry, were then prioritized.

Furthermore, it was essential that all the core questions would provide the necessary input to adequately answer the three research questions. For example, the question "What do you see as the biggest benefits of AR?" helped us understand the positives of AR and is directly linked to research question 1. The question "What might prevent you from using AR?" gave the interviewee the chance to reflect on limitations and barriers that could suggest why mass adoption has not yet occurred, and what might be needed for it to happen. This was highly relevant for both research question 2 and 3. "From the perspective of your role, is the time right for this tech?" was a question that allowed the interviewee to openly discuss when they thought the time was right for AR and the factors that come into play. This provided valuable insights for the answering of research question 3. A complete table consisting of all questions, the reasoning behind them and the specific research question they were relevant for, can be found in full detail in appendix III. Lastly, it is worth noting that the interviews were conducted in English. Firstly, because the interviewees were of different nationalities. For example, USA, India, France and Germany. Secondly, so that interviews could be automatically transcribed using transcription software.

3.2 Interviewees

The interviewees were sourced from a range of different backgrounds, from Ph.D. in Geology to MSc in technology management. They worked for different companies in different countries, ranging from Coca-Cola Hellenic bottling company to Bosch. One thing they all had in common was experience or knowledge about AR solutions in their organization, combined with industrial knowledge in their area of expertise. Another thing many of them had in common was the ability to influence their organization because of their title and/or job description. For example, one of the interviewees had the title *global head of innovation* in a large, multinational company. Another interviewee had the title *head of industrial digitalization;* thus, it is fair to assume their opinions to some degree has influence on the company's digitalization strategy. Our interviewees were primarily sourced based on their knowledge or influence in industrial-oriented use cases, as opposed to AR technology in the private sector. As discussed earlier, it was our belief that industrial use cases showed the most potential. This was therefore consciously decided, as we primarily wanted opinions on AR for industrial use. Table 1 contains a list of the people interviewed, along with their title, their industry and the name used to refer to them later in the thesis.

Title of interviewee	*Industry*	*Cover name*
Channel account manager, IoT and AR	Industry 4.0 Solutions	Interviewee 1
Head of industrial digitalization	Manufacturing research	Interviewee 2
PhD, researcher	Manufacturing research	Interviewee 3
Group asset care manager	Beverages	Interviewee 4
Global head of innovation	Semiconductor	Interviewee 5
Key account manager	Industry 4.0 Solutions	Interviewee 6
Regional sales manager	Predictive maintenance	Interviewee 7
Director, acceleration center	Agriculture	Interviewee 8
Customer success manager	Industry 4.0 Solutions	Interviewee 9
Vice President, Research and Development	Various	Interviewee 10

Table 1: Interviewees

The search for these interviewees started by googling keywords such as "Augmented Reality and manufacturing." This led us to news stories and articles about specific companies that had started or tried AR recently, often with quotes from company representatives. We then reached out to the company representatives on LinkedIn for an interview. Furthermore, we also used LinkedIn directly to find people in the AR space by searching for phrases such as "Augmented

Reality expert." This method was effective in the sense that it allowed us to quickly find people with knowledge about the topic we were interested in. However, the method was potentially flawed in the sense that many of our interviewees publicly highlighted their interest and experience with AR, resulting in potentially biased opinions about the future of AR. The realization led us to be extra cautious when interviewing. Additional to the proactiveness mentioned in the prior sub-chapter regarding accurate interview questions, making sure all the interviewees reflected thoroughly on things such as barriers and limitations for the technology were of importance. All interviewees received questions that allowed them to present opinions on this.

The interviewees approach to the questions varied. Some answered concisely to the exact questions asked, others spoke in length beyond the initial question that was asked. Typically, when they went beyond what was initially asked, it was based on the explanation of the thesis, given when the interviewees were initially contacted. In other words, the information provided was still highly relevant to the research question and in many cases answered questions we had planned to ask in the first place. Follow-up questions were also often asked when relevant answers would benefit from additional input and explanations. As a result, each interview evolved differently. The length of the interviews varied from half an hour to an hour. Regardless of length, all interviews had in common that all core questions were answered, which in turn led to plenty of valuable data to analyze.

3.3 Data analysis

Defined steps of data analysis were developed to ensure a clearly outlined process. The first of which was to analyze secondary data. This was to develop a deep understanding of AR and the factors that may come into play when evaluating its future. Then, we conducted interviews that provided new information and insights, in addition to solidifying already discovered data. Transcribing and interpreting the interviews would further improve this understanding; hence it was our next step. This process began by analyzing each interview individually, extracting opinions, reflections and experiences that revealed valuable information.

Next, the information was categorized into themes based on content similarities and our overall understanding of the subject. Such themes ranged from *user opinions, trends,* and *success criteria*. This was manually reviewed to extract valuable information that could add to the discussion of the research questions. Once all the information was organized into sensible themes, the themes were again reviewed, aggregated, and fine-tuned so that we got a clear understanding of how the findings should be structured. This fine-tuning helped us lay a ground basis for a deeper discussion. Finally, we created a disposition based on four aggregated themes: *hardware, UX and software, culture and society, and company*. This entire process provided the necessary data for answering the research questions but was not exempt from threats to validity and reliability. Overcoming threats to validity and reliability was therefore an integral part of the research design.

3.4 Issues of validity and reliability

Validity and reliability are important considerations when evaluating any research. Validity is the integrity and application of the methods undertaken and the precision in which the findings accurately reflect the data. Reliability on the other hand, describes consistency within the employed analytical procedures (Long & Johnson, 2000).

Ensuring reliability is inherently difficult to manage given the nature of semi-structured interviews. This is because even if interviewing one person twice, with the same questions, the interviewee is unlikely to produce the exact same response both times. We argue however, that objectively stated questions and basing the interview on the interview guide improved reliability.

More can be done to ensure validity. Threats to validity in qualitative research are typically discussed with regards to three types of bias, hereunder respondent biased, researcher bias and reactivity (Kriukow, 2019). Respondent bias was a concern in that interviewees might not have been truthful in what they shared. A CEO could for example have biases towards positive aspects of the technology the company had implemented, an employee might have had worries about sharing their perspective if it does not align with leadership, and a seller of AR solutions might have been overly positive towards its future. Researcher bias on the other hand refers to the influence of our previous knowledge and assumptions on our study. An example of this is the fact that we were, prior to the research, enthusiastic about technological developments. Reactivity refers to the role as a researcher and the influences that come from our physical presence in the research situation, and possible influence on the data (Kriukow, 2019).

To further minimize the potential influence of these three biases, we implemented several strategies as suggested by Robson (2002). Firstly, triangulation, which involved the use of multiple sources to enhance the rigor of the research. Triangulating various forms of secondary data, along with our interviews, helped to counter the threats to validity. Secondly, getting feedback and opinions from others through peer debriefing. Throughout the research process, we had meetings with the supervisor and discussed our research with other third parties. The feedback and criticism from these meetings allowed for a more objective view and helped to become aware of limitations of the study, which is likely to have reduced researcher bias (Kriukow, 2019). Thirdly, member checking, which involves returning to respondents and presenting to them material such as transcripts, accounts, and interpretations (Robson, 2002). Sending the whole interview transcript for review or conducting a validation interview were methods that were deemed too demanding for the interviewees, given their busy schedule and level of importance within their companies. However, some respondents were asked about specific things that needed clarification, to ensure that our interpretations corresponded with what they meant. An audit trial was another effort incorporated into our research to ensure validity. This meant that we kept a full record of our activities while carrying out the study, including raw data such as transcriptions of every interview, all notes and documents used throughout the process, and details of our data analysis (Robson, 2002). A final effort to reduce respondent bias was to anonymize the interviews and make the interviewee aware of this. It was important that the research design did not expose those researched to embarrassment, pain, or any other inconveniences (Saunders, 2016). Anonymization might have also minimized the issues of respondent bias presented earlier.

All these efforts helped solidify the research design. Furthermore, the research design itself has helped to clarify how the findings of the thesis were gathered. With that in mind, our findings are ready to be presented and discussed.

4. Findings and discussions

Augmented Reality has existed for quite some time, and therefore, the way in which the research questions are discussed is highly dependent on what timeframe is considered. The benefits of implementing AR technology were different decades ago, compared to today, and again compared to the future. The same goes for limitations and barriers. Furthermore, research question 3 specifically relates to when the time is right for mass adoption of AR. This makes it logical to follow a timeline for the discussion of the findings, as a way of more clearly determining exactly when the time might be right, as well as clearly seeing the development of benefits, limitations, barriers, and other factors that have an impact on "the right time for mass adoption of AR." Consequently, this section is divided into three sub-chapters. As explained by interviewee 2, AR advancement is unpredictable, as opposed to linear. Thus, the time span for each sub-chapter is not equally divided. The division is made based of an overall overview of the number of different use cases, technological emergence, pivotal moments for the development of AR, as well as the amount of literature in the field. Figure 7 is used to visualize some of the influential points of AR history, and to easier understand the time-categorizations. Although the exact dates in the future are impossible to predict, we distinguish between near and far distant future. The next 5-10 are thus labelled *near future*, while *far distant future* is +/- 40 years from now.

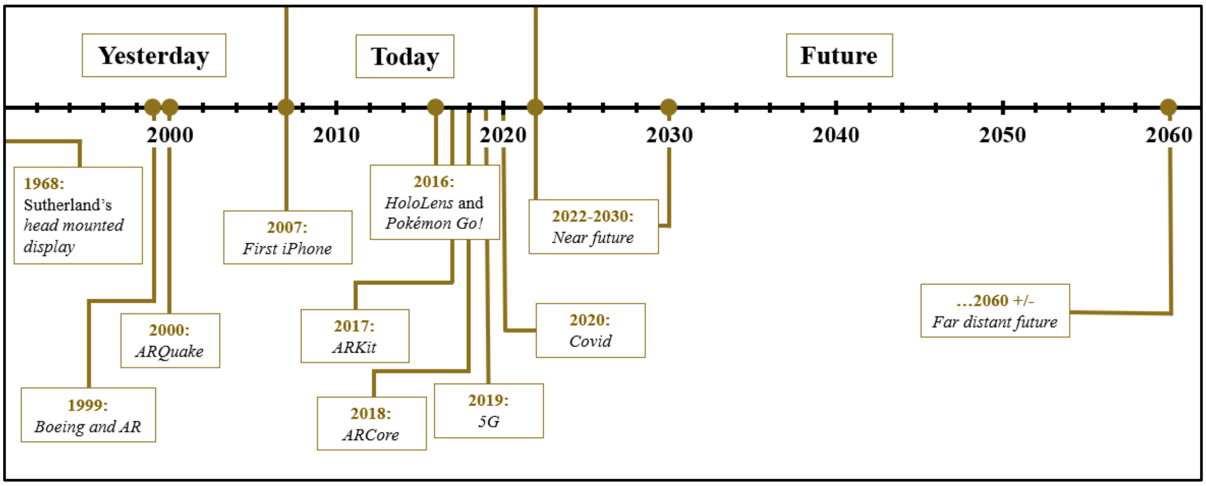

Figure 7: Historical timeline

Since there is a significant difference between the time eras, each era will have a slightly different focus. Firstly, the discussion will revolve around *yesterday's era* i.e., pre-2007. This era was different in terms of available AR enabling technology, such as good processing power or smartphones. Therefore, barriers and limitations will be emphasized in yesterday's era. In

2007, the first widely adopted smartphones came out, thus allowing for significantly more AR use cases. As previously mentioned, smartphones are the most accessible hardware used for AR applications today. This could be considered a pivotal moment for the adoption of AR, hence marking the start of the second sub-chapter *today's era,* 2007's-2022. This section will be the largest, and will, based on RQ1 and RQ2, cover benefits, limitations, and barriers, as well as necessities required for mass adoption of AR. Limitations and barriers will be divided based on whether they relate to hardware, user experience and software, culture and society, or company. Lastly, the future of augmented reality will be discussed. Here, the discussion will revolve around how limitations and barriers can be overcome and the factors that need to be in place for mass adoption to occur. This part will mostly be relevant to the second part of RQ2, as well as laying the grounds for answering RQ3 in greater detail. The limitations, barriers and factors creating the basis for that discussion are taken from the *today's era* – section. The chapter will also open a discussion about the far distant future. Finally, the section will highlight technologies that are worth considering with relation to our overall research question. There will by the end of this chapter be given a clear answer to RQ3: "When is the right time for mass adoption of AR in business processes?" Afterwards, implications for the research, future research, and the limitations of this research will be discussed.

4.1 Yesterday

4.1.1 Use cases and benefits

As emphasized by our second interviewee, AR technology has been around for a long time; often in ways people do not normally think about. This should be kept in mind when considering RQ1 in yesterday's era. As we defined in chapter two, Augmented Reality is overlaying digital content onto the physical world. Nevertheless, as emphasized by interviewee 2, it is important to understand that the term *Augmented Reality* can be used more broadly; any alteration of the reality we know can thus be called an "Augmented Reality."

An example of this was the World War 2 RAF Lancaster Bombers. The plane had strong spotlights mounted underneath, shining onto the ground beneath the plane. This allowed for precise feedback of whether the plane was at the right altitude, resulting in better aim when bombing (Forkasiewicz & Postlewthwaite, 2018). Figure 8 illustrates how this technology worked.

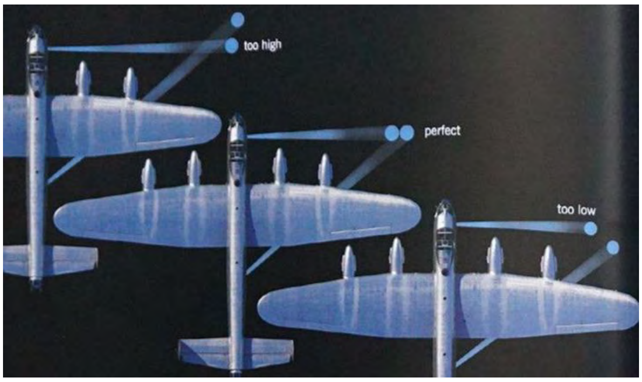

Figure 8: RAF Lancaster bombers (Forkasiewicz & Postlewthwaite, 2018)

Another example of augmenting the reality in yesterday's era is the 1960's *smell-o-vision* technology. By pumping evocative smells through tubes at a movie theatre, the viewer would be able to *smell* the movie, thus resulting in a more vivid movie experience (AFI, 1960). With respect to RQ1, these are both examples of unique ways in which businesses could benefit from implementing AR technology. The specific nature of these examples also highlights one of the major limitations of yesterday's AR, processing power.

The processing power available was far worse in yesterday's era compared to today. Therefore, it is fair to argue that the possible use cases were more limited. As described more thoroughly in the history part of chapter two, there were some emerging use cases in yesterday's era, such as the first versions of the head-up display (Vaughan-Nichols, 2009), the first head-mounted display for wiring instructions (Caudell & Mizell, 1992), and the first AR game (Carmigniani et al., 2011). These inventions showed some potential in their respective fields, such as Baird and Barfield (1999) who found AR to be more effective than manuals, but overall, the use cases for AR were mostly isolated and limited in yesterday's era. Few people knew much about AR, and the benefits of the technology were rarely revolutionary, not going beyond their isolated use case. As time went by, an increasing number of people were made aware of AR. However, our findings suggest that the primary users of the technology in yesterday's era were limited to researchers and particularly technology interested individuals. Considering RQ1, although use cases of this era highlighted potential benefits of implementing AR, it can be argued that the technology was not mature enough for the benefits to truly reveal themselves, due to several barriers and limitations.

4.1.2 Barriers and limitations

Our findings suggest there were several barriers and limitations that hindered the widespread adoption of AR in yesterday's era. Considering RQ2, these barriers and limitations can be categorized into three factors: hardware, user experience, and potential market.

By *hardware*, we are referring to physical devices required for AR solutions to function. The most common examples in 2022 are smartphones, tablets, as well as head-mounted displays such as the HoloLens. These devices all consist of components such as processors and cameras. However, the hardware available in yesterday's era was significantly weaker and less available than what we are living with in today's era.

Every AR system does include a computer in one form or another. A processor that coordinates and analyses sensor inputs, stores, and retrieves data, carries out the tasks of the AR application program, is key for AR system (Craig, 2013). Given that yesterday's era had significantly less powerful computers than today, the possibilities for AR were fewer, or required significantly more hardware. What we now define as "simple tasks" required much more hardware in yesterday's era. For example, figure 9 displays a user and his point of view of the first AR game, ARQuake (Didier, 2021). The equipment the user wears weighs as much as 16kg. The left picture shows the player, while the right picture shows the player's point of view.

Figure 9: ARQuake (Didier, 2021)

Conclusively, the hardware of yesterday's era was both a limitation, in the sense that a computer system could only handle certain amounts of data, and a barrier in the sense that development of AR applications and use cases were particularly difficult with the available hardware at the time.

Secondly, yesterday's era did not have a focus on user experience. By *user experience*, we are referring to an end-user's subjective feeling on how well an AR application is perceived. A good user experience leaves the end-user satisfied with the AR experience. The applications at the time, such as the first AR game, were difficult to adapt and had little integration with most people's daily life. For example, interviewee 2 stated "[AR] was more about technology rather than the user experience." During our interviews, it became clear that this is still an issue in today's era, which we will go into more detail about later.

Lastly, another important limitation of yesterday's era, preventing mass adoption of AR, was the lack of potential markets. Both people and companies did not yet know much about the technology. The use cases were few, and the potential markets were therefore slim. Furthermore, the excessive cost of AR solutions was influential in the potential for adoption. For example, when asked about AR's past, interviewee 2 explained the following: "it's just that now it's becoming a lot more affordable, a lot more accessible. And I think that is where I've seen the change, the change has been the cost of the devices to display the content on."

Conclusively, when considering RQ3, our findings suggest that our defined timeframe "yesterday's era" was not the right time for mass adoption of AR. This was due to several factors: the limited use cases, underdeveloped hardware, low focus on user experience, people, and companies' lack of knowledge about the technology, as well as the excessive cost of AR solutions. Improvement of such factors proved to be important for AR development moving forward.

4.2 Today

4.2.1 Use cases and benefits

Since the first iPhone launched in 2007, the emergence of smartphones has been swift. "Everybody" now has gadgets such as smartphones or tablets available. This revolutionary shift in providing easy access to a device capable of utilizing AR technology has had a significant impact on the number of AR use cases. Applications that were almost unimaginable before can now be accessed by "everybody" with a phone.

With the wealth of data and information provided by Big Data and the Internet of Things, the benefits of AR as an end point for data visualization became more feasible. Such data visualization can result in a range of benefits for businesses. For example, a business owner can, with AR, look directly at a machine and see a live graph of its power consumption in combination with a graph of the price for power. This allows the business owner to get a better picture of the company's assets. Different gadgets such as weather meters, GPS trackers and other statistics can now all cooperate and be neatly visualized with the use of AR. Figure 10, an illustration from Baur (2017), is an example of how such data visualization could look like.

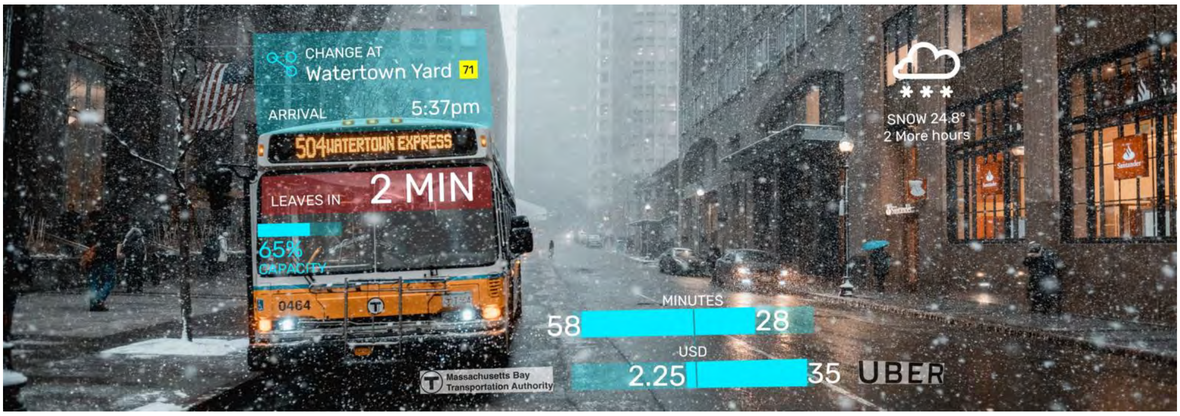

Figure 10: Augmented reality example (Baur, 2017)

Apart from enabling AR to function as an end point for data visualization, our findings with regards to RQ1, are that benefits of implementing AR technology in business processes have started appearing in greater number in *today's era*. For example, most of the use cases utilizing the benefits of visualization, instruct and guide, and interaction as described in chapter two came to fruition in *today's era*.

The benefits of AR are no longer hypothetical or limited in scope as in *yesterday's* era, they are now put into practice by many companies and in various industries to increase efficiency and reduce error. For example, when Boeing started using Upskill's AR solutions for wiring harnesses, they saw a reduction of wiring time by 25% and a reduction of error rates effectively to zero (UpSkill, 2016). Such tangible benefits were also examined by others, such as Forrester Consulting. The company assessed the total economic impact of the AR product *Vuforia* (Forrester, 2019). Vuforia is a software development kit for creating AR applications, both for mobile/tablets and head-mounted displays. Keeping RQ1 in mind, this gives a solid understanding of the many benefits of implementing AR technology in business processes today.

By conducting interviews with companies that had AR experience as well as surveying companies that had no experience, Forrester was able to conclude that AR reduced new hire training by 50%, reduced overtime spending’s by 10-12%, reduced spoilage, rework, and waste by 5-10% as well as reduced the time it took to create technical documents by 60%. Furthermore, Forrester found that organizations using Vuforia experienced improved customer satisfaction, reduced contact center costs and improved safety and working conditions. Finally, Forrester concluded that the overall return on investment (ROI) was as much as 172% for the companies examined.

During our interviews, several of these benefits were mentioned and emphasized. For example, interviewee 8 explained that AR enabled better training and showcasing of big agriculture equipment such as grain storage units; “Doing training was really difficult, you know, with a tractor or piece of movable machinery, you could drive it somewhere. People could play with it. You load it back up on the trailer, you take it back. Couldn't do that with this equipment.” Another interviewee, interviewee 3, emphasized their experience with safety, customer satisfaction and efficiency by using AR: “there was a lot of positive feedback because keeping their hands free made them do the work in a more safe way” …” [resulting in] better customer satisfaction, and [AR] improved their productivity by 15, some cases 20%. So, they were much, much faster.”

Much of this increase in efficiency is due to AR’s ability to keep the workers focused on one task. For example, instead of switching back and forth between lengthy pages full of information and the task at hand, the user can receive that information when needed, in context, in a more intuitive, engaging, and efficient manner. Interviewee 4 emphasized this by stating “[AR] allows the user to keep his hands free … so he can do the actual manual labor without having to use paper. Before that, we used to have a paper solution.”

Conclusively, our findings indicate that the benefits of AR in today’s era are many. Better data visualization, increased efficiency, saved costs and reduced errors are some of the findings discussed here. Although today’s era provides many promising insights with regards to RQ1, several barriers and limitations still complicate the potential for mass adoption.

4.2.2 Barriers, limitations, and necessities

Hardware

Our findings indicate that one of the biggest limitations hindering mass adoption is hardware. This was the most frequently mentioned limitation in interviews, primarily with the head-mounted hardware. AR is demanding, it requires a lot of data and processing power. To meet these technical requirements, head-mounted hardware compromise by being designed in a way that for many is seen as too clunky, heavy, and cumbersome to use. Interviewee 8 said that “for non tech people it’s unbelievably threatening.”

This leads to users not wanting to wear it for several reasons. For some, they don’t want to wear it in fear of breaking the new gadget, while others think wearing the heavy HoloLens is tiring. Interviewee 3 did however follow this up by saying weight is not a problem at shorter workstations. Other reasons are seemingly more trivial. Interviewee 9 explained how real estate showed great interest in AR to do viewings with clients on the other side of the world. An issue that revealed itself, however, was people not wanting to mess up their hair wearing it. People simply do not want to wear any form of headgear unless they must. Interviewee 5 illustrated this by pulling up a pair of normal glasses, highlighting how small, light and fashionable they are, and explaining how despite this, people would not want to wear them unless it was for their eyesight.

This idea of “threatening” technology applies not only to the dimensions of the hardware, but also how it is used. Interviewee 8 addressed the fact that people are not used to AR, i.e., how it asks you to do things differently, such as giving voice commands. Features that are inherently beneficial can be seen as threatening given how unusual and unfamiliar they are. For many users it is not easy to use simply because it is not an everyday habit. As explained by interviewee 6, “it takes time for people to take HoloLens, understand it, understand what is happening in the in the field of view.” Users that have been used to their methods for many years are unwilling to learn vastly different methods, especially given how most of them must learn from scratch, with minimal to no knowledge of what AR is and how to use it. The tech is new, but also immature, in the sense that it still has many technical challenges and limitations. As mentioned, the size of the hardware is a compromise to its technical challenges. The processing power and specs required to display the digital content, latency and connectivity with others, and power consumption, are all examples of technical limitations that are currently being addressed by hardware deemed too clunky for many. This is one of many examples of how technical limitations, in turn, lead to personal barriers from potential users, adding further points of consideration with regards to RQ2 and RQ3.

It can be argued that many of these limitations are not relevant when utilizing smartphones instead of head-mounted displays. However, smartphones come with their own set of limitations. Several interviewees pointed out that handheld devices such as smartphones are inferior to head-mounted displays in some ways. For example, interviewee 6 emphasized the fact that “you don’t have three hands.” Keeping the workers’ hands free can be important and in some instances necessary for AR solutions to be feasible. Interviewee 8 emphasized this by stating “We had people that are 100 feet up in the air trying to replace a bearing. Asking them to hold an iPad and turn around just doesn't work very well.”

Furthermore, with head-mounted displays you are displaying information directly to the end-user’s peripheral, which can be more efficient than having to reach for a screen all the time. Smaller screens can also lead to problems of scale. For example, when looking at a big installation in AR, the end-user will get a more immersive experience and thus a better feel for the size of the installation when using head-mounted displays. This can be particularly important in situations where sales or convincing is a focus.

No matter what setting an AR solution is used in, or on what device, any AR solution requires software in one form or another. This, in combination with the end-user’s experience of AR is another important factor for the mass adoption of AR. The next section will thus discuss these factors.

UX and software

Software can be defined as instructions for a computer of what to do and how to work. In contrast to hardware, software is easy to replace since it is not physical. Every computer needs some form of software, i.e., instructions, to function. *User experience* (UX) on the other hand, is about the end-user’s experience with a technological solution. It is often tightly connected to software, since the end-user’s experience heavily relies on how well the software is built, and the applications it can help develop. Therefore, this section will discuss both UX and Software.

Building on RQ2, our findings indicate that today's AR solutions have noticeable flaws when it comes to today's user experience and software. The first limitation we want to highlight is that for most AR solutions of today's era there has been a technology focus, leading to little focus on UX. Interviewee 2 said he had bought a lot of head-mounted devices throughout the years and seen first-hand how the devices have slowly evolved "from being technology focused to being human centered," iteration by iteration. By this he was referring to the fact that that so far, the devices have been developed mainly with a focus on technology rather than making it as appealing as possible for the end user. Today's AR solutions can be compared to that of the early personal computers. They were a breakthrough in terms of technology but difficult to use compared to today's computers. Progress for AR advancements is now no longer just a matter of technical improvements, but also one of user experience, which still has a way to go for mass adoption to occur.

Another limitation with today's AR solutions is latency. This is especially relevant in cases where processing power is accessed through a cloud service rather than through the hardware of the AR device, a growing trend for reducing hardware size. Latency is a measure of time delay, and will naturally influence how end users experience AR. In a perfect product, the end user would be able to look at an object and instantly see augmentations on top of that object. If there is latency, the augmentations will not be accurately displayed at first, which is crucial for the overall experience and if the end user is dependent on data being visualized as quickly and accurately as possible.

Lastly, a limitation with today's AR software solutions is that the AR device often isn't integrated enough with the environment it is used in. As explained by interviewee 3, an AR researcher at a manufacturing facility of boilers in Germany, todays AR tools are often based on the assumption that workplaces are static. For the boiler industry, that is not the case. Due to a lot of manual manufacturing processes, the assembly line is constantly changing. Generic solutions such as QR codes for anchoring augmented models prove therefore to be inefficient in such manufacturing plants.

All in all, it can be argued that the need for improved user experience and software add additional limitations and barriers for AR and are factors that need to be addressed if AR is to flourish and reach a point of mass adoption. This will be important especially when considering people's opinion and perception of AR, which is another massive hurdle to overcome. The following sub-chapter, culture and society, discusses this hurdle.

Culture and society

By *culture*, we are referring to norms, beliefs, and values of a population. By *society*, we are referring to people living together in a community. This section will address implications of culture and society on AR, specifically limitations, barriers, and necessities for mass adoption. Firstly, we will discuss how cultures and societies were influenced by AR during today's era and with that reflect on the pace of which adoption has happened. This is specifically important for answering RQ3, as it gives an idea of where people's consensus is heading. Then, this section will move on to specifically pinpointing the implications culture and society has for RQ2.

AR has been around for decades, but until recently, few really knew what it was. It is only in the past 10 years that it has started reaching the headspace of investors, companies and to some extent the general public. One of the reasons for this was the release of Pokémon GO in 2016. The video game introduced AR to a much wider audience, and thus influenced communities' opinions on AR technology. Our findings indicate that such opinions and familiarity with AR are important prerequisites for mass adoption. Furthermore, several of the interviewees cited the app as an eyeopener for the possibilities of AR and that their transition into AR was sparked by it.

Some of the interviewees also started experimenting with AR when the first HoloLens was introduced in 2016. The potential for AR was clear and although the hardware had its limits, predictions for the future of AR were bold. The introduction of HoloLens, Facebook buying the VR company Oculus, rumors of Apple working on their own AR device, were all signs that convinced several interviewees that mass adoption of such technology was eminent. Interviewee 8 predicted in 2017, that by 2020 we would have eyeglass sized hardware. "I was telling people we need to be ready by 2020, cause the hardware will be here, our competitors will also understand that to differentiate ourselves, you're going to need it [AR] as part of your training and service." If RQ3 were to be asked amid these trends and speculations, chances are predictions would be bold, and the belief could be that the time for AR was right. Development did, however, go slower than expected. For example, there was anticipation around HoloLens 2 in 2019, and although it improved several aspects of the first iteration, it ultimately fell short of expectations. Covid-19 also posed challenges for the development of and potential for mass adoption of AR.

With Covid-19 hitting the world in 2020, investments stopped, halting innovation and progress. Furthermore, companies became more risk averse and unwilling to invest in the technology, despite AR's inherent potential of overcoming challenges of the pandemic. "Intuitively you'd think it's the other way around, that it would take off, but it's [AR head-mounted display] too heavy." Interviewee 9 went on to explain how Facebook highlighted several technical problems with VR that would take many years to solve. When asked if the same applied for AR, the interviewee said, "It's even worse, more difficult." Given how investments halted, it can be argued that Covid-19 is a major reason as to why progress has been slower than expected pre Covid-19.

Another factor that dialed interviewees expectations back, is the realization that people tend to show resistance towards disruptive technology. Despite apps like Pokémon GO and smartphones making AR experiences more accessible, people and more importantly end-users and decision makers are still often skeptical of new technology, and their knowledge is still limited. As explained by interviewee 5, AR meets resistance in the enterprise, and it meets resistance when trying to educate people on what it is and how to use it. This cultural phenomenon is thus a barrier for mass adoption of AR.

The interviewee went on and said that "disruptive innovations [such as AR] start off small and then boom they go and set the standard." For many front-line workers in industrial companies for example, the mindset is that AR is here to replace them, not enhance them. Interviewee 6 stated "When bringing this technology on the field, we need to bring an added value to the end user." They need convincing that AR will help them work better and more efficiently. Even then, however, it can be difficult to convince people to use it. As previously mentioned, it is "scary" technology, it is unfamiliar, workers have their methods and are reluctant to change even if it means higher productivity. Interviewee 6, responsible for introducing an AR solution to fieldworkers was often met with resistance. "He's like, I don't care. I don't want to be more productive. I don't want to be more efficient. So **** you."

Another reoccurring theme in the interviews was the discrepancy between different age groups' willingness to learn about and utilize AR. Generally, younger people are more open to new technologies. Interviewee 5 explained it with the following example:

> If I put a headset in front of him [9-year-old son] and I put a headset in front of my colleague, a professor in a busy university, same box. OK, the professor takes four

> months with a lot of pushing to go open the box. With my son, I can't keep him away enough. He's like all over it like a fly on a soup.

The difference being that the experienced ones need a manual, while younger people are willing to try, fail and figure it out by themselves, as part of the process. The interviewee argued that it is the next generation, those with fresh eyes, that will bring adoption. The older generation already have methods that work for them. When already successful, they lack the will to change. The interviewee further stated “Fully fed lions. They don't need to hunt, so they won't hunt, right? So, like this, people who are already successful, they're not gonna change.” Consequently, the interviewee suspected that change is not necessarily going to come from inside the company, but from the outside. Pressure from the outside, either from consumers, clients, or new employees, is therefore seen as a potential key factor that needs to be in place for AR to reach mass adoption.

A significant extension of the age-related barrier for adoption is the fact that decision makers are typically within the older age group. C-level executives are those that make the final decision to invest in AR. As stated by interviewee 9, “You can convince the young people, you can convince the engineer, but he's going to have zero power.” The interviewee argued it comes down to decision makers not having the right mindset. Regardless of whether they know about AR or not, it might take upwards of 20 years of convincing, testing and prototyping before committing to AR. A major manufacturer was used as an example to illustrate this fact. The interviewee highlighted how the company was considered to be at the forefront of technology but still needed five years of convincing before committing fully to AR.

All in all, with relation to RQ2, our findings indicate that there are several cultural and societal limitations and barriers that hinder mass adoption. Those are the historically slow adoption rate due to lack of knowledge, resistance to implementing new technology, people’s willingness to change if they do not feel obliged to, as well as the minds of decision makers. The next sub-chapter will further examine AR adoption with regards to companies’ perspective.

Company

The reasons for the slow AR adoption are plentiful. With regards to RQ2, many of the barriers come down to company concerns and resistance. Firstly, people’s personal reasons for resisting new technologies, as described in the previous chapter. Secondly, reasons that relate to the company perspective of investing in and implementing new technologies. Ultimately, the barriers from a company’s perspective come down to concerns regarding return on investment. This mainly boils down to three factors, the cost of investments, ROI being difficult to measure and an increased level of risk aversion in companies.

Regarding the cost of investments, there are many expenditures to consider. A company might have to invest in data architecture to get data flowing to the AR devices easily and seamlessly. Furthermore, companies might have to reallocate workforce to work on this, alternatively hire a new type of employee. Interviewee 2 explained this by stating:

> When we've got the data architectures right and if you go on any of the big recruitment sites at the moment, you'll see that an awful lot of the large companies are beginning to ask for a capability known as an enterprise architect.

Preferable hardware like the HoloLens can also quickly get expensive. Interviewee 6, a key account manager of a technology company in France, stated “I don’t like using tablets or iPad. However, for change reasons, it’s better to begin with that kind of hardware.” This statement was referring to the fact that companies need to be convinced before investing. The interviewee further said:

> …scaling this kind of tool in a factory, in a company that has plants all across the world, it's like a huge investment they are not ready to do yet, as we don't have enough proofs that the return on investment is here.

Similarly, software can also get expensive. Development of apps, whether internal or external, and costs of AR software. It can be argued that the cost of software is easier to justify when scaling to more plants or factories, if the application and use case works across multiple factories. Nevertheless, it is another cost to consider, and increases the barrier for commitment even if the ROI seems clear.

However, the ROI is often not clear in the eyes of management. As exemplified by interviewee 8, who was given the opportunity to test AR for training, “the renewal came up and they’re like [management], well, what's the ROI on this? Right. And I'm like, well, we're just getting started. We're looking at transitioning over.” For many of the use cases of AR, it can be difficult to measure the ROI clearly for management. A publication from BCG suggests there is a lack of speed with which companies (including their senior management teams) are embracing new technologies and ways of working. This is often due to the lack of tangible results from big investments in systems and technology (Hutchinson & Aré, 2018).

To conclude today's era, benefits became clearer as use cases significantly increased with the introduction of new hardware, and with companies starting to embrace AR. As use increased, so too did the realization of the breath of limitations and barriers, which in turn reduced the overwhelming positivity towards the future of AR. Interviewees indicated successful implementation of AR and an enthusiasm for the technology in their own companies but point to several factors that need to be addressed if AR is to truly reach wider acceptance and mass adoption. Technological limitations, peoples’ mental barriers and world events like Covid-19 are all examples of this. Conclusively, despite AR being deemed promising, the time for mass adoption of AR has not been reached yet.

4.3 Future

As our findings indicate that the limitations and barriers for AR in today’s era are plentiful, this chapter aims to discuss the second part of RQ2; ways in which these limitations and barriers can be overcome for mass adoption. We will distinguish between early and far distant future. Therefore, the first part of this chapter refers to the *near future*, i.e., 5-10 years. The second sub-chapter, *far distant future*, is the period in 40+- years. In the far distant future sub chapter, we will add the final points of consideration needed before finalizing our answer to RQ3. Finally, this chapter will address the limitations of the thesis.

4.3.1 Early future

Hardware

The findings clearly suggest a need for improved hardware, both in terms of size and technical capabilities. Interviewees highlight a few trends and viable solutions in the next 5-10 years, that could see the hardware achieve the necessary improvements for mass adoption.

A major technological advancement that many points to, is 5G. By 5G, we are referring to the fifth-generation mobile network, a successor to the 4G mobile network that most people have access to today on their mobile phones. 5G is up to 100 times faster than 4G, "creating never-before-seen opportunities for people and businesses" *(Ericcson, n.d.).* Technical limitations such as latency and a substantial need for processing power, can thus be solved by moving the processing power to the cloud and using 5G/6G to transmit all necessary data free of latency. This could, by extension, be a solution to people's desire for unobtrusive hardware as well. As interviewee 9 pointed out,

> You cannot have the computer power in this little thing [ideal head-mounted display] you know, so we're waiting for 5G or 6G to stream the data live to the two eyes, you know, 4K to the two eyes. That's a lot of data.

Similarly, interviewee 10 discussed how 5G can lead to new opportunities by eliminating many of the current limitations and barriers. "I would say that the 5G technology will be an enabler maybe for the next wave of augmentation data today, limited by time delays [latency] and other kind of barriers." With many signs pointing towards big tech companies currently working on AR projects, we could see dimensions of the hardware being brought down to more acceptable levels, and 5G could play a key role in accomplishing this. Reducing latency is integral for the UX. Future development of additional factors regarding UX and software are discussed in the following chapter.

UX and software

As described in *today's era,* there have been noticeable flaws with today's AR systems with regards to UX and software. Apart from latency, discussed in the prior sub-section, this is due to UX being given a lack of priority and AR's need to integrate with the environment. The interviewees were however optimistic about the future of these barriers and gave valuable thoughts on the time to come and the factors that can and need to be in place for AR to flourish with regards to UX and software.

Firstly, regarding the technology orientation of today's AR solution, it is going to be more of a focus on the user experience and the user interfaces of AR devices. Interviewee 8 pointed out that this has become a greater focus in schools; studies such as *human-computer-interaction* as opposed to just *computer science* have emerged and will continue to emerge in the coming years. It is thus fair to argue that in the coming years, there will be more people specialized in and contributing to an improved user experience. These thoughts were vividly supported by interviewee 8, who stated "I don't care how fancy it is [AR projects] or what things you can make it do. The human digital interaction of that is really critical to making a good AR experience and having people that think that way." Interviewee 3 concluded that if the user experience is bad, nobody is going to use it.

Secondly, AR devices are often not integrated enough with the environment they are being used in. Coming back to interviewee 3, boiler assembly lines were used as an example of pointing to the fact that to battle such integration issues, software solutions that capitalize on deep learning algorithms may prove efficient. As the interviewee stated, "the augmented reality tool needs to understand the environment." If the AR device understands the environment just like humans do, it can display more relevant information and work in a more efficient way. Deep learning algorithms are still new, and interviewee 3 concluded that we will have to wait 5-10 years before such algorithms will be impactful with AR. This could prove important in industrial settings where the environment changes. We argue that compared to other factors discussed, deep learning is not equally necessary for AR to flourish in most cases, as opposed to the other factors discussed.

An additional factor that suggests further improvement to UX and software in the coming years, are the improvements and simplifications to app development. App development has improved somewhat in the past few years and is likely to improve further as AR solutions based on low-code approaches become better. These solutions are often in the form of software that allows people with little technical skills to relatively quickly develop and deploy AR solutions into their business. For example, one could use a generic app to scan QR codes, one for each AR experience. Interviewee 8 explained that this makes much more sense from a business perspective than creating one specific AR application for each AR experience. Interviewee 2 emphasized that such software has gotten more intuitive to use than before. It is thus fair to argue that as these generic solutions continue to improve, more companies and people will be able to deploy AR applications. With more companies being able to develop and deploy AR applications, the higher the probability of innovative solutions and methods appearing, that in turn can influence and inspire more companies to develop better applications. That could also lead to a change in people's perception of AR, along with other factors discussed under culture and society.

Culture and society

As explained by Tim Cook, the CEO of Apple (TechlifeCoach, 2016), for there to be mass adoption of AR, there needs to be a general acceptance of being connected to a computer. As discussed previously, a barrier to adoption is people’s unwillingness to try AR, to learn it, to use it. There is a lack of understanding for what AR is capable of. People are not well educated about AR. The mindset of decision makers and users alike is often one of resistance, skepticism, and fear of the unknown. Interestingly, many interviewees cite Apple as a possible solution to the problems voiced by Tim Cook himself, and essential for when the time for AR can be considered right.

The reason being that people need a more polished product. There needs to be a change in attitude towards AR. It needs to become more acceptable and normalized, in the larger population. An enabler for this, pointed out by several interviewees, is if a big and somewhat “perfectionistic” company such as Apple releases an AR product for the masses. Apple releasing an AR product has been rumored for several years, and pointed out by some of the interviewees, Apple only releases “polished” products. This could explain the long wait and suggests that it still may take a while for such a product to be released. However, when a polished product is released, we suggest it may have a trickle effect on all aspects related to the rate of adoption.

Although the opinion of the public could have a significant impact on rate of adoption, it is still likely going to emerge in businesses first and foremost. Our findings indicate this is because of money. As explained by interviewee 7, “the buying pattern of a B2C is not the same as B2B.” Companies buy things if it adds value to the company, while consumers buy things for other reasons such as showing off or entertainment. Interviewee 9 explained that when computers came, it first started off as a company thing. After a while, the regular consumers were able to afford it, bring it home, and showcase it to the rest of the family. This generated interest and adoption in the private market which in turn increased people’s knowledge and attitude towards the technology for professional use. A similar process is happening these days in industrial companies with AR.

Our findings also indicate that outside stimuli are needed to change people’s perceptions and attitude towards AR. For example, interviewee 9 explained that when politicians talked about the importance and potential of Artificial Intelligence (AI) a few years ago, the perception and attitude towards AI changed, resulting in an uptick of interest and investments in the field. If influential politicians and institutions such as the EU get convinced, they can be a significant driving force for AR. A similar effect can come from influential companies such as Apple or Amazon, once they release more “polished” AR hardware. The combination of big technology companies paving the way and people leaders talking with enthusiasm about the technology are therefore very important factors for changing people’s perception about AR. This change of perception will in turn increase the demand and thus increase the rate of mass adoption in the future. This point was highlighted by interviewee 5, who compared AR innovations with the discovery of fire. The analogy may help understand the arguably slow development of AR – it simply needs a big spark to spread to the masses.

Our findings indicate that there is a noticeable difference in people’s attitude towards using AR. When asked about experiences regarding different age groups and AR acceptance, it became clear that the “younger generation” has a more open mind and have an easier time to adopt AR technology as opposed to the older generation. For example, interviewee 6 explained that both young and old people can use the technology, but their experience is that younger people are more open to use it. As time passes, more and more people in the workforce will have familiarity with technologies such as AR, which arguably will lower that barrier in the years to come. This shift in the workforce will help “normalize” the use of AR, which in turn will help speed up the implementation.

One or more of these factors will likely help change people's perception of AR, normalizing the use of it, which in turn can help AR reach mass adoption. With this, we can with greater certainty predict when the time is right for AR, as asked by RQ3. The factors concerning the company should however also be addressed beforehand.

Company

There are many ways companies' adoption rate of AR can be affected in the years to come. When looking at the second half of RQ2 as well as RQ3, it is particularly important to consider the perceptional change of influential workers and stakeholder when it comes to AR. Whether it is change that can lead to more companies investing in AR, change that can increase the chance of success with AR, changes that lowers entry barriers of implementing AR, or change that incentivizes commitment to AR technology.

Up until this point, companies have typically been slow and hesitant when adopting AR technology. Interviewee 4 explained their slow adoption with several factors, including

1. Reducing risk by starting small

2. The need for good preparation, given the immaturity and unfamiliarity with AR

3. A need for internal success stories: finding the right use cases that lead to positive business outcomes and proving ROI.

For example, convincing management can be difficult when ROI is unclear. For AR to flourish in a company, we argue that it is a crucial factor to find use cases that leads to a clear ROI. Interviewee 5 stated that "we tie innovation to business outcomes." This refers to how technology changes all the time, but the focus on business outcomes such as efficiency stays the same. "These things [business outcomes] are all universal and time tested. 100 years from now they are not going to be changing." In short, implementation must be driven by business outcomes, and preferably outcomes with a clear ROI.

Interviewee 8 explained how AR was exceptional for training, but that it was not enough to convince management, as the benefits were more difficult to quantify. Once they shifted to sales and got big sales with the help of their AR solution, there was a wider acceptance and belief in the technology. The interviewee elaborated by saying:

> When we kind of shifted to sales, that ROI became pretty easy because kind of our third year of doing it, we had 6 million in AR assisted sales for $30,000 investment in it and they're like OK, this makes sense. I think the challenge and what's gonna limit AR into the future I think is finding the application for it within your business to generate that type of ROI.

It should be noted that this company had a great starting point for testing out AR, more so than most. The company was large enough to consider AR "not too big an investment to test out for a year." For many companies, the bottom line is not big enough to logically allow a risky investment like AR, as it requires too much of the overall revenue.

In the next 5-10 years, however, it can be argued that challenges and costs affecting ROI will decline, lowering the barriers for investing. For example, as hardware continues to develop, the costs of it may be reduced. Moreover, it can be argued that more success stories are on the horizon. With big players like Volvo Group in the Nordic market (PTC, 2019) highlighting the value of AR, it is possible that more companies are willing to try it, as the dependence on internal success stories decreases and use of the technology becomes more acceptable.

Giving people a better idea of what AR is and how it can lead to positive business outcomes is one of many factors that can change the mental state of the various groups within a company. As interviewee 2 said, "The lack of take up I think is because, the people with the cheque books these days don't understand the power of the technology." He further suggested that this will change in the future, as new employees enter companies:

> I think so over time as the people that have grown up with this technology get into those positions of power there will be higher take up faster, take up broader, take up of this technology. So I think absolutely it's [AR] got a role to play. It's just we need to educate people about the value that it can bring.

New employees may lower the barrier in other ways in the coming years too, in that there will be an increase in the technical knowledge required to successfully implement AR solutions. New graduates learning the necessary skills, being more curious about the technology and figuring out ways to solve the necessary problems, could boost companies' willingness to invest. More educated individuals will eventually be entering positions of power, and with new employees bringing more positivity towards AR, the mindset of companies and the workforce within may change.

As the previous chapter suggests, a cultural shift may certainly have an impact. So too will demand. It could be argued that once we get a wider acceptance for wearing head-mounted displays, it will shift the mindset, not only of the companies, but important stakeholders as well. Clients, customers and next generation employees alike may begin to expect AR solutions, or at least see it as a favorable trait of those that use it. If AR becomes necessary to stay competitive, more companies will follow suit.

Findings reveal several factors that may influence companies' stance on AR in the near future. Every industry should consider the digital space moving forward and with the influence of factors discussed in this chapter, it is likely that AR will be given more attention moving forward. Taking the entire chapter into consideration, we argue that RQ3 can be given a fair assessment. However, technologies relevant to AR in the far distant future should also be considered before reaching a conclusion, as they may strengthen or weaken the position of AR in the future of business.

4.3.2 Far distant future

As explained in the introduction of the thesis, augmented reality can be categorized under the umbrella of "industry 4.0" solutions. When considering our third research question, when the time is right for mass adoption, it is therefore important not to overlook the emergence of other industry 4.0 solutions that can either strengthen or weaken AR's influence on business in the far distant future. This section will thus aim to shed light on such key technologies.

Since AR is categorized under the "extended reality" umbrella, this section will begin by discussing VR's potential impact on AR in the far distant future. Then, we want to briefly pinpoint three emerging technologies that we believe may have implications on the far distant future of AR. Those technologies are neural brain chips, artificial technology (AI), and advanced robotics.

Virtual Reality technology

Even though VR has not been discussed thoroughly throughout this thesis, it is especially important not to overlook the far future prospect of such a seemingly similar and perhaps competing technology. After all, many of the challenges with AR today also applies for VR. During our interviews, it became clear that AR has more potential than VR. For example, interviewee 5 stated that "Augmented reality is 1000 X bigger compared to VR when it comes to applications, because VR is good in a classroom … but when you are in a factory floor, you really have to see what's ahead." Interviewee 5 later stated that he believed that the different extended reality technologies could co-exist, allowing end-users to quickly switch back and forth between AR and VR. Furthermore, several of the interviewees agreed that the money lies in AR due to more use cases. This suggests that there might be more development in AR than in VR moving forward, which leads us to believe that AR will become the dominant technology of the two, in the future.

Nevertheless, one could say that the aim of all mixed reality solutions is simply to enrich people with more information and efficient everyday solutions. However, there comes a point where even AR solutions are not information rich enough. For example, as interviewee 9 explained "this [AR] is before the connection to the brain." The statement sheds light on an important aspect: AR might just be a steppingstone towards other more advanced technologies. AR may also be an integral part of these future technologies, such as neural implants.

Neural implants

When talking about neural implants, we are referring to the insertion of a computer chip, permanent or temporary, so that humans can connect and communicate with each other or machines, using brainpower. Getting to the stage where information technology is connected directly to the brain arguably require a lot of technological iterations. For example, two of the interviewees mentioned that AR lenses could be a thing in the future, with available hardware getting better every day.

Some companies are already working on neural implants. An example is the company NeuralLink, who are working on solutions to connect information technology directly to the brain. The company started lining up clinical trials in humans in 2022, and the co-founder has stated that “[NeuralLink] will enable someone with paralysis to use a smartphone with their mind faster than someone using thumbs” (Musk, 2021). If this statement proves to be correct, it can impact the future of AR in many ways. For example, instead of having to configure machines with interfaces based on AR, the future technicians can connect to the machine and simply “think” or “act” how the machine should be configured, potentially making AR obsolete in industrial settings.

Furthermore, if technology ever reaches a point where information can be transmitted into the human brain wirelessly, many of today’s use cases would no longer be needed. The individual can simply think of a topic and utilize the endless information flow of the internet to get their answers. For example, with AR one could learn how to assemble a machine with augmented arrows and highlighted parts. With an advanced neural implant on the other hand, one could eliminate the need for such augmentations – which part goes where is automatically fed from the work instructions to the brain. Such futuristic solutions are arguably dependent on extremely advanced software; hence it is often discussed in relation with artificial intelligence.

Artificial intelligence (AI)

As defined by McCarthy (2004), “[AI] is the science and engineering of making intelligent machines, especially intelligent computer programs.” The term has been around since Alan Turing asked the question “can machines think?” (Turing, 1950). With the emergence of better computers and processing power, AI has become increasingly common in our everyday lives. There is, however, a distinction between *weak* and *strong* AI (IBM Cloud Education, 2020a). While weak AI enables advanced, practical tasks to be solved such as Apple’s *Siri* or autonomous vehicles, strong AI is a theoretical form of AI that is still under development. The potential of strong AI is still unclear, as it is still in an early phase of development. However, as explained by IBM Cloud Education (2020b), “Strong AI aims to create intelligent machines that are indistinguishable from the human mind.”

Interviewee 3 emphasized that in the future, AR devices will utilize AI to understand the environment. Not only does this mean that AR applications can become far more accurate, but it also allows for a more personalized, and thus effective AR experience. As explained by interviewee 2,

> Information will be personalized to you, so it will understand who you are. It will understand what you want to see. It will understand what you have seen before and therefore don't need to see again, or perhaps want to reinforce it. There will be better and easier ways of interacting with it [AR].

On the other hand, strong AI might have negative effects on the use of AR in the future. Since AI allows software and machines to learn and adapt, it is fair to argue that the need for human inspections can be reduced. For example, a machine infused with AI might control the speed or use of materials based on what is needed in a more efficient way, thus reducing the stress and maintenance need compared with a regularly operating machine. Furthermore, the combination of advanced robots and strong AI could make human inspections entirely redundant. However, the opposite may also be the case. With AI reducing the need for human interaction, so too will the expert knowledge needed to repair these machines, if the machines inevitably do need to be serviced by a human. With a deskilled workforce, AR can be the solution. The human does not need to know what to do, as the AR application can guide them through the process in detail. The human would only need to know how to use the AR application. In other words, the need for a system that can guide the human – in this case an AR application, will increase, for the few occasions human repair of the machines is required. Another technological advancement that may reduce the need for human interference is advanced robots.

Advanced robots

A robot is a machine that can complete tasks autonomously. By using electric “senses” (sensors) and “instructions” (algorithms), it can process input from its surroundings to complete its tasks (Søraa, 2022). An advanced robot on the other hand, has superior perception, integrability, adaptability, and mobility, compared with a conventional robot (Küpper et al., 2019). Often, this is due to incorporated artificial intelligence software, that allows the advanced robots to learn how to best perform the tasks it is created for.

In the publication *the factory of the future* (Küpper et al., 2016), BCG argued that due to greater use of robots and computerization, the number of jobs in assembly and manufacturing will decline. This suggests that the quantity of AR in production might decline as well, given that AR is mass adopted before such waves of layoffs. On the other hand, it can also imply that the workforce left in such jobs are more dependent on AR solutions in their day to day. A concern about the future of AR fronted by interviewee 8 was that if AR is not mass adopted before technology such as advanced robotics reach wider adoption, there is a chance that many AR use cases such as inspections will die. On the other hand, interviewee 3 argued that due to the complexity of different assembly lines, it is very hard to have autonomous robots replacing all human interventions. He argued that in the future, AR can be used as a tool to train robots. For example, a worker can record himself using AR to perform a task. He can then feed that information directly into an advanced robot that utilizes AI to learn from the worker.

Other extended reality solutions, brain implants, AI, and advanced robotics can all be considered enablers or barriers for the far distant future of AR. Future use cases are impossible to predict to perfection, and other emerging technologies not mentioned here can thus have an unforeseen impact on them all. Nonetheless, the examples mentioned in this section plays an important part in understanding and predicting the prospect of mass adoption of AR. In the next subchapter, we will discuss if and when we think there is a time for mass adoption, as stated by RQ3.

A time for AR?

To reiterate, the final research question aims to uncover when the time is right for mass adoption of AR. This includes the possibility that the time for AR has passed, and the possibility that it will not happen at all. Certain findings could suggest this being the case. First, the fact that development is taking longer than expected. The excitement surrounding AR was significant many years ago and predictions were bold. Now in 2022 however, it has yet to happen. Therefore, one could have doubts about the technology ever reaching its necessary level of advancement for mass adoption to occur.

In this case, other technologies might develop faster, to the point of making AR as we know it, obsolete for most of its now promising use cases. For example, if smart factories become completely autonomous as described previously with AI and advanced robots, it removes the need for humans entirely. When questioned about it, interviewee 2 quoted someone else saying that the factory of the future will have two employees, a man and a dog. “The man will be there to feed the dog and the dog will be there to make sure the man doesn't touch any of the machines.” The interviewee considered it a dystopian future. Nevertheless, he entertained the idea and claimed that even in this scenario, the unattended machines would have to be repaired by a human at some point. A plausible future is one where AR functions as the delivery system for the information needed to effectively repair machines. Furthermore, the interviewee addressed the possibility of deskilling the workforce, and explained that the worker would not need any expertise about the machine itself, as all necessary information needed could be delivered through AR. The interviewee said it this way: “I can actually become a bit of a dumb worker because as long as I know how to use the system [AR], then the system retains the knowledge. A bit like with sat NAV.”

Findings suggest that there are indeed very difficult challenges ahead for AR. Many of which have been discussed in this thesis, giving a good idea as to why it is taking longer than expected. Regardless, the consensus of the interviewees is that it will happen. With curiosity of when this might happen, all interviewees were asked to give a prediction as to when mass adoption of AR might occur. Answers varied from 2-10 years. With our overall understanding of AR, its current state and the factors that need to be put in place, it is our belief that the right time for mass adoption is in the *near future,* i.e., in the next 5-10 years.

Lastly, many interviewees claimed that when mass AR adoption happens, it would make a considerable impact, not just for the success of AR, but on society as a whole. As interviewee 9 stated

> I talked with some very high-level tech people recently and everybody's agreeing. It's going to be 5-10 years before we have a, you know, consumer VR/AR, but then it's going to change everything, you know, like a phone changed everything. This is going to be even more intense and deeper change, you know.

This coincides with what Tim Cook, CEO of Apple said about AR in his interview at Utah Tech Tour in 2016 (TechlifeCoach, 2016): “It will almost be like eating three meals a day. It will become that much a part of you. A lot of us live on our smartphones, they are very important to us. AR is going to be big.” The idea is that it will fundamentally change how we interact with the world around us. Information can be displayed everywhere around us. Arrows guiding you where to go, as an example. Perhaps even more interestingly, there are use cases and applications that are yet to be discovered. Similarly, to how social media has changed society, or how google maps changed how we got from point A to B. Things that are unknown now, will have a significant impact in the future and AR will likely play a role in some capacity, given its disruptive nature. In short, mass adoption of AR will happen and will have significant implications on society, as well as on businesses and their processes.

4.4 Implications for business and future research

As introduced in the beginning of this thesis, it is important that businesses do not overlook the technologies of the fourth industrial revolution, including AR. These emerging technologies are not merely incremental advances on today's digital technologies, they are truly disruptive – they upend existing ways of sensing, calculating, organizing, acting and delivering (Schwab & Davis, 2018). Beyond adding to existing research and giving weight to scholars, it is our conviction that, based on this research, businesses risk missing a tremendous opportunity if AR is not considered for their future operations. By highlighting the opportunities and challenges that AR can bring, this thesis has given companies a better basis for evaluating the technology. Companies should build on this knowledge, by staying proactive and up to date on the developments and trends that are likely to result in mass adoption of AR within the next 10 years. In doing so, companies are better prepared to take advantage of AR and thrive in the future.

Although our research has found out if, and when mass adoption is likely to happen, we believe other factors may also have an impact on how and in what rate it happens. To better understand how the adoption takes place and accelerates, future research could address factors such as geography and culture in combination with technological infrastructure, current methods of labor and economic conditions. It should also be considered that future use cases and benefits are subject to change. Thus, future research could address how factors such as technological or organizational change affect use cases and benefits of AR. New limitations, barriers and necessities are likely to arise along with new use cases, which could also be examined further. Finally, the next sub-chapter will address limitations to our research, which future research in this field can also benefit from.

4.5 Limitations of the thesis

This thesis has some limitations that may have had an impact on the quality of the research, as well as our ability to answer the research questions properly.

Firstly, it is important to address the interview process. The interviewees were found by searching online for keywords such as “augmented reality expert” or “companies using augmented reality.” This led us to a range of articles that had quotes from company representatives or experts. We then reached out to those individuals through LinkedIn. Furthermore, we also searched directly on LinkedIn for individuals with “augmented reality” in their profile. Even though this led us to people with expertise or experience in the field, it is worth noting that these people were publicly showing their interest or expertise in the field, which might indicate they had a positive and perhaps biased opinion of the technology. To battle these issues, we could have interviewed more people that were less enthusiastic and had less technological knowledge of AR. Preferably, individuals who felt “forced” to use the technology in their everyday life, or who had no say in the company’s decision to implement an AR solution. Such people proved to be difficult to find within our time and resource constraints.

Nonetheless, such measures could have given more nuance to the data, which perhaps could affect our answers to the research questions. Furthermore, all the interviews were conducted online, thus reducing our understanding of factors such as body language and cultural differences. Since we interviewed people from many different geographical and cultural backgrounds that had varying English capabilities, there is a chance that some of the findings were somewhat misinterpreted. We have worked systematically to reduce this misinterpretation, although there is always a slight chance.

Secondly, as described in chapter three regarding validity and reliability, consistency in the interviews have been a focus. However, due to the semi-structured nature of the interviews, finding a perfect balance between being consistent in the interviews and allowing the interviewees to answer freely may have influenced the research. If we had a larger sample size, it would have influenced the quality of the research. Furthermore, we, the authors of this thesis have a keen interest in technological innovations, and even though we have focused on not interpreting the interviews enthusiastically, it is worth noting that the methods we have chosen might have a degree of bias even if unconsciously so.

Thirdly, picking another approach in terms of research methodology might have added weight to the conclusions, or resulted in a different conclusion. For example, including some elements of quantitative data, such as financial information from companies utilizing AR. Lastly, utilizing software for sentimental analysis could perhaps have reduced the biases in this thesis as it would have given a more objective analysis of the interviews. However, this was not prioritized given the time and resource constraints.

5. Conclusion

This thesis has aimed to answer the question "is augmented reality the future of business?" by looking at factors affecting the potential for mass adoption of AR in business processes. Our findings indicate that yes, AR will have a significant role in the future of business once limitations and barriers preventing mass adoption are overcome.

The research has included a combination of primary and secondary data, for an extensive understanding of AR and its implications on business processes. By dividing our findings into three different time periods, hereunder yesterday, today, and future, we have examined the technology's benefits (RQ1), its limitations and barriers, and the necessary factors for mass adoption (RQ2), as well as a discussion on when the right time is right for mass adoption (RQ3). Our findings indicate that the benefits can be categorized into the three following categories: visualize, instruct and guide, and interact. These benefits lead to positive business outcomes such as improved efficiency, reduced costs, and increased sales. Furthermore, by enhancing real life surroundings, AR has the potential to completely change how we see and interact with the world around us. There are, however, limitations and barriers possibly explaining the lack of adoption in businesses, as mass adoption has yet to occur. These factors have been categorized as hardware, UX and software, culture and society and company. As a result, it will take time before we reach mass adoption of AR. When it comes to hardware, our findings indicate that the available devices are not sufficient for mass adoption. Head-mounted displays is preferred over smartphones but is currently too cumbersome and heavy for most people. Heavy investments and rumored products from companies such as Apple, Microsoft and Amazon are likely to improve this aspect. Regarding the user experience and software, our findings for example indicate that up until now there has been a focus on improving the technology rather than the end-users' experience, an area of importance that is getting more attention now than before. Furthermore, there are cultural and societal factors such as people's willingness to adopt this disruptive technology that needs to change. Finally, companies need more convincing to adopt AR. This can for example come from success stories clearly proving ROI, or through a generational shift in the workforce.

Our findings suggest that a combination of these factors and trends can alleviate the limitations and barriers over the next 5-10 years, leading us to believe that mass adoption will occur within the next 10 years. Consequently, we emphasize that companies should seek to educate themselves and their workforce on the opportunities for AR in their business, and to be proactive in the years to come, to ensure a competitive edge. To better understand how the adoption of AR will take place and accelerate, future research could address other factors that may influence adoption such as geography, in combination with technological infrastructure, current methods of labor and economic conditions.

Regardless, our findings indicate that AR adoption will happen, and as Tim Cook, CEO of Apple puts it, “It [AR] will happen in a big way, and when it does, we’ll wonder how we lived without it” (TechlifeCoach, 2016). It will spread like wildfire, it will change the game significantly, similarly to how the smartphone did, and companies need to be prepared.

6. References

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7. Appendix

I: Figures and Tables

II: Acronyms

3D	3 Dimensional
5G	5th Generation of mobile telecommunications technology
AR	Augmented Reality
CAD	Computer Aided Design
MR	Mixed Reality
ROI	Return On Investment
RQ	Research Question
VR	Virtual Reality
XR	Extended Reality

III: Interview questionnaire

The following questions were used during the interviews. Since the interviews were held with a semi-structured approach, these questions were mostly for guidance and not all the questions were answered by every interviewee. The first eight questions were prioritized and answered by everyone, the latter were mostly used when fit as follow ups, or when time allowed it. The second column is the motivation for asking the question, while the RQ column is what Research Question the question mostly relates to.

Question	Motivation for question	RQ:
Could you give a quick introduction to your background and current role?	Get an overview of the person's experiences, how it relates to AR and their knowledge of the topic.	-
How do you feel about AR? Past, now, future	Understand their perspectives and experiences with AR through time.	1,2,3
What do you see as the biggest benefits of AR	Understand the positives of AR from their perspectives	1
Challenges of implementing AR?	Understand specific limitations and barriers	2
3 most important factors for AR to succeed as a technology for companies?	Understand how to overcome the barriers	2
What might prevent you from using AR?	Uncover limitations and barriers	2,3
From the perspective of your role, if and when is the time right for this tech?	Gather perspectives and insights on if and when the time is right for AR	3
Suggestions for who we can talk to?	Finding potential leads	1,2,3

Why should/shouldn't companies use AR?	Uncover benefits, limitations and barriers	1,2
What may hinder companies from being successful with AR?	Uncover barriers of implementation	2
Defining moments in history so far, for the adoption of AR. What defining moments need to take place in the future for it to be the right time for AR?	Give weight to the different time - era's defined. Relevant insights for all RQ's	1,2,3
What AR use cases were available in the past, what were the alternatives to AR?	Understand the history of AR	1,2

Follow up on a positive to-AR: Why is now the right time, why not earlier? What hindered companies from adopting this 20 years ago?	Understand the history of AR, to understand the future of AR	1,2
What AR use cases are available now, what are the alternatives? What are companies typically doing?	Understanding today's era	1,2
What is likely AR use cases in the future, what alternatives might there be?	Understanding tomorrow's era	3
What prevents mass adoption of AR in industrial companies?	Uncover limitations and barriers	2
What can't AR do? Past, now, future?	Uncover limitations	2
What limitations of AR can be overcome in the future?	Uncover limitations that may not be an issue in the future	2,3
Do you believe companies will take advantage of AR in the future? What alternatives might they choose?	Gather perspectives on the future of AR in businesses	3
Can you talk about your use of AR?	Understanding the person's and company's use of AR, benefits, limitations and barriers, and their specific role with regards to AR in the company	1,2
How has AR improved business?	Uncover benefits	1
What has been challenging?	Uncover limitations and barriers in their specific case	2
What is not working?	Uncover limitations and barriers in their specific case	2
Is the time right for AR in your company? Why, why not?	Is the time right for AR, from the specific company's perspective	1,2,3
What needs to change/improve for you to consider AR?	Uncover factors that need to be in place for mass adoption to occur	2,3