Investigation of the potential of Augmented Reality technology for sustainable mines of the future.

A qualitative study, development and demonstration of augmented reality applications.

Bachelor’s thesis in Mechanical Engineering, Industrial Engineering and Management, and Automation and Mechatronics.

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Preface

This study has been conducted during Spring 2020 at the Department of Industrial and Materials Science at Chalmers University of Technology. It is the final step of the bachelor's degree in Mechanical Engineering, Industrial Engineering and Management, and Automation and Mechatronics.

During the project, some interviews have been organized with engineers, a sales director, a service manager, a geologist and an associate professor, all working within the mining industry or having valuable knowledge of this area. They wanted to remain anonymous, but we would like to thank them all for their time and the useful information they provided us with. Also, we would like to thank Liang Gong for putting the Microsoft Hololens device at our disposal, this helped a lot in the realization of the project and the achievement of certain goals.

Furthermore, we would like to thank our supervisor, Gauti Asbjörnsson, for guiding us through this project, assisting us in finding the needed resources, being engaged and helpful.

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Abstract

The fourth industrial revolution has already led to digitalization gaining ground in the mining industry. As a part of this, augmented reality is being considered a possible tool. This thesis, therefore, explores its potential to be used in the mining industry meaningfully.

This study was based upon using previous work in the field along with conducting interviews with experienced people from the industry. The information gathered was then put through the process of a decision matrix to determine which of all generated ideas would be worth developing.

The project resulted in the exploration of three augmented reality applications, out of which two were fully developed within the project's time frame. For developing the demos, Unity's game engine "Unity" was used in combination with the "Vuforia" software, providing image recognition through cameras for augmented reality purposes.

A first demo guided users through the process of assembling parts. The second one was an augmented reality version of a checklist, allowing users to see work tasks right in front of their eyes. The third demo that was not developed, gave an operator the ability to be guided through their work by an expert remotely. This expert would be able to see through the operator's field of view, and interact with it through different drawing tools.

The assembly demo was tested both on a smartphone and a Microsoft Hololens headset, where it was determined that settling with the cheaper smartphone would be the best option for most companies, unless they wish to use it for developing augmented reality applications themselves. This is because the experience of using a first generation Hololens is compromised considerably mainly by its too small field of view.

Finally, the conclusion is that augmented reality has a place within the mining industry, even if the investment cost of purchasing the specific headset for it is not yet justified. The mining industry currently suffers greatly from the difficulty of convincing competent workers to relocate themselves to quarries far from civilisation. Augmented reality would allow for easier self-training of workers, while the experts could provide aid remotely when needed.

Keywords: Augmented Reality, AR, mining industry, mines of the future, industry 4.0, sustainable.

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List of abbreviations

Below is a list of all the abbreviations, and their respective explanation, used throughout the report.

AR- Augmented Reality
AV - Augmented Virtuality
CAD - Computer-Aided Design
CAQ - Computer-Aided Quality
HDD - Hand-Held Device
HMD - Head Mounted Display
LCD - Liquid-Crystal Display
PDA - Personal Digital Assistant
VR - Virtual Reality

1 Introduction

The materials extracted from mines are used in consumer products in various ways. This need for resources creates the necessity for enormous operations of extraction and purification of the mined materials. In Sweden alone, about 27,5 million tonnes of ore, of various minerals, was mined in 2018 and generated about 40 billion SEK in revenue in the same year [1]. These large operations do in turn create a need for large amounts of resources such as electricity, space and qualified workforces. In Sweden, the mining industry is the third-largest consumer of electricity with a consumption of 3678 GWh in 2019 [2].

Despite the large and increasing operations, the mining industry has been criticised for a few reasons. One of the main reasons is the impact on the environment, and even though mining companies in the Scandinavian countries as well as in the rest of the world are working with sustainability, it is more often with economic and to some degree social sustainability [3], [4]. Moreover some have questioned some ethical aspects of the industry, such as governments favoritizing the industry. The Chilean government is for example letting mining companies exploit water sources [5] and in turn contaminating the sources also used by local farmers [6]. Another ethical dilemma the industry is facing is the safety and health of the workers. Mining operations in India have led to workers becoming infertile from inhaling harmful particles due to working in quarries [7]. These hazardous conditions are not only present in Asia. According to a study performed by the National Safety Council in 2016-2017, the mining industry has the third-highest rate of preventable fatal work injuries among industry sectors in the US [8].

The increased demand for the materials produced by the mines as well as the large quantities produced means that the costs for running the operations are immense. In the mining industry it is essential to keep the operations up and running to as large of a degree as possible since the smallest interruptions generate big costs for the companies [9]. This in addition to it becoming more expensive for mining companies to hire and remunerate their workforce creates a need from the industry for tools aiding with minimizing the disruption of their operations. In light of the aforementioned information, it comes as no surprise that the mining industry is cautious in implementing new technologies. A small negative fluctuation in the revenue could potentially result in several million SEK of losses which in turn makes industry itself very conservative and slow moving [10]. Despite the difficulty in implementing new technologies, there is still a demand for new solutions to ease the transition to a more sustainable operation.

The augmented reality (AR) field and its applications have started to get a real foothold in many industries today. Industries like games, education and touring have started to apply the technology in a variety of ways [11]. The game PokemonGO utilizes AR to display objectives in the real world and did it with great success [12]. The AR technology is not only used for amusement but is also applied in medicine to help people with impaired senses to regain the function of them again [11]. However, in other industries that put higher quality requirements on the technologies, like the manufacturing industry, the technology is still in its infancy and still has some challenges to work out before it can successfully be used on a larger scale [13].

There have however been some examples where the technology has been used successfully, despite there being high quality requirements, resulting in lowered costs for the organisations implementing them. For example, Porsche lets local mechanics receive remote guidance from experts with the use of AR when performing complex maintenance [14]. This enables Porsche to let their experts efficiently share their knowledge all across the globe without them having to travel to where they are needed. Thus reducing emissions and traveling costs as well as increasing the efficiency of the workshop. This type of solution could carry over to the mining industry without much alteration. This would enable mines to get the much needed expert help to their remote mines without the need for experts to travel there, resulting in reduced costs and more efficient operation.

AR is not a silver bullet however. It is not always obvious whether it adds value in the areas it is applied to or if the problems could be solved in more efficient ways with other technologies. For example, some information could be better displayed on a simple computer screen rather than in the view of the operator. Another factor to take into consideration is to select what information is to be displayed since too much information could potentially overwhelm the user and cause them to perform worse [15]. Furthermore, there are still technical and economical limitations to AR technology [16], [17].

Depending on the situation an array of different solutions can be used to display the AR application. Head-mounted displays (HMDs) might be utilized if the hands are needed, but if there is no such requirement, handheld devices (HDDs) could be more suitable. There are many different variations and manufacturers of both display options which are used to varying degrees [13].

To summarize, the mining industry operates with high costs, big volumes and little to none allowance for errors. This in turn makes the industry, and the companies operating within it, conservative and cautious with disruptive technologies. The field of AR is starting to gain traction within several industries and there are already some applications that have the potential to carry over to the mining industry and thereby creating value for the industry. However, there are a lot of problems in the industry that AR might not be the optimal technology to solve. Therefore it has to be evaluated whether AR brings any value to applications that are to be developed.

This thesis stems from three other theses conducted during 2019 at Chalmers University of Technology, in Gothenburg Sweden, as well as RWTH Aachen in Aachen Germany. Two of the theses were conducted at RWTH Aachen and one at Chalmers. The Chalmers project titled “Augmented Reality for a Sustainable Mining Industry” looked into what potential applications AR could be used for in the mining industry and also generated concepts for some applications [18]. The two theses written in Aachen both titled “Augmented Reality for the Mines of the Future” also investigated potential uses of the AR technology in the mining industry [19], [20].

The objective of this thesis is to further explore the potential of AR's application in the mining industry. Taking into consideration the needs of the industry, and the characteristics of it, whether AR technology can add any specific value and whether the technology is mature enough to be exploited on a notable scale.

1.1 Purpose

The purpose of this study is to determine possible uses for AR technology specifically within the mining industry, as a tool for improving its operations. The study will involve creating concrete demonstrations, or demos, from a selection of potential AR solutions to provide insight into how they could affect the work performance.

1.2 Approach to the problem(s)

It is unknown whether AR technology has a viable application area within the mining industry. In addition, if such an area were to be found there is also the question of how the implementation of AR would be executed.

An evaluation is done on the current state of the mining industry through interviews with different stakeholders and literature studies. This is done in part to determine what experiences previous AR projects have had and what expectations different parts of the industry have of the technology. But more importantly, it is done to see what areas of the mining process are suitable for an AR solution and what needs it can fulfill. Based on the results of the various interviews and studies, a set of concepts are generated. Some are based on suggestions and theories from the interviewees and from last year’s thesis. From this set, three are selected to be developed, according to different restrictions and requirements outlined in “3.3.2 **S**creening of the generated concepts”.

1.3 Delimitations

A delimitation when determining the overall usefulness of AR is to focus on the mining industry. Another delimitation is the decision of which demo(s) to focus on where multiple factors are taken into consideration. These include the balance between niche versus a broad area of application (flexibility), development time and the end-user cost. Lastly the chosen demos were limited according to the time and resources available to the thesis group.

Although there are a variety of different hardware options for displaying the AR applications, this project will be based on Microsoft’s Hololens. The reason behind this decision was the possibility of using a unit available at Chalmers.

2 Theory

The theory chapter aims to provide the necessary information regarding the theories, frameworks and subjects the report incorporates. This is done to help the reader understand the results and the process of coming up with the results better. In addition, it is to provide the reader with a deeper understanding of why choices were made during the project.

2.1 Augmented Reality

AR is a technology used to enhance or augment the real world by filming it through a device and thereafter displaying computer-generated objects on top of it [21]. Azuma et al. [22] talks about three requirements in order for an application to be considered AR. Those three requirements are that the application has to run in real-time, has to be a mix of virtual and real images and has to have the virtual objects be dependent on some real-world objects. AR can be both interactive, for example with the use of hand motions, or simply display different objects in the real world.

In 1994 Paul Milgram and Fumio Kishino created *Milgram's Reality - Virtuality Continuum* [23], which displays to what degree a technology is interacting with the real world or a completely virtual one as seen in figure 1. AR is the closest to the real world whereas Augmented Virtuality (AV) and Virtual reality (VR) creates virtual worlds with little to no dependency on the real world.

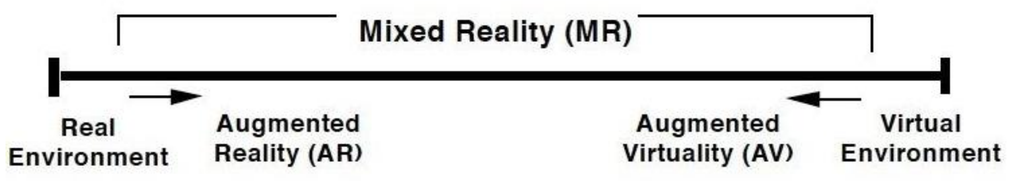

Figure 1. The Milgrams's Reality - Virtuality Continuum displaying how different reality altering technologies relates to the real world as well as to how they relate to one another [23].

AR is not necessarily limited to visual enhancement of the real world but can also be applied to enhance other senses such as smell, touch and hearing [24]. Furthermore the augmented technology field does not only add objects or senses to the use but it can also be used to remove objects from view. This is commonly referred to as mediated or diminished reality and could be desirable if a doctor wants to see through the skin of a patient in order to determine diagnosis [25].

A simplified way of looking at how an AR application operates is to think of it as three different components. One is some sort of real-life data feed, most commonly a video feed. This will provide the application with an environment to augment. The second object is a tracking object. A tracking object is what the application will "look" for and thereafter display the third object, the rendering [27]. The rendering could be a wide variety of things, for example a 3D-model, see figure 2.

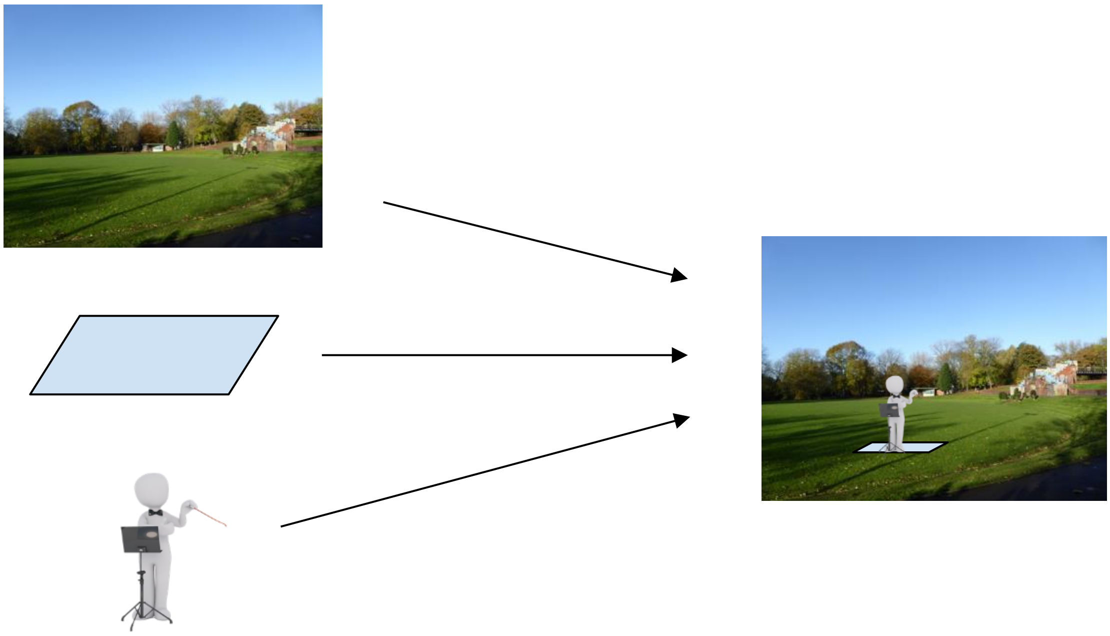

Figure 2. A simple model of how an AR application is structured. The application is continuously looking for a predetermined target through the video feed. When the target is found the model is displayed on the target. From [26] . CC-BY

2.2 Head-Mounted Displays (HMD)

Head-mounted displays, or HMDs, are tools used for viewing AR or VR that are in some way attached to the head of the user. Some hardware is very closely related to a pair of glasses, some are integrated into protective gear, such as helmets, some use straps whilst some have more resemblance to hands-free headsets which are attached to the ear. Common to all HMDs are that they are, to varying degrees, in the line of sight of the user. This is in order to display information to the user in an easy way. Furthermore also common for all HMDs are that all of them are reactive to the movement of the user [28], [29].

There are two major types of HMDs which differ in terms of how they display the information as well as if they interact with the real world or if they display a digitally generated one. Those that interact with the real world utilizes a transparent display to show any objects or information their connected software provides them with or to display digitally generated objects in the real world. Instead of transparent displays, the other type of HMDs has displays in the line of sight of the user, such as LCDs. These are more commonly used digitally generated worlds, like the ones used in VR applications [28], [29].

2.2.1 Microsoft Hololens

The Microsoft Hololens is the first HMD developed by Microsoft and was initially released in 2016. Hololens is utilizing a transparent lense in the line of sight of the user and is worn like a pair of glasses. It is run on the Windows 10 operating system and utilizes six different sensors in order to capture the environment around it. One Inertial Measurement Unit, which contains a gyroscope used by the lens to understand how it is tilted, one depth camera, one HD video camera, four microphones, four cameras for environment data collection and one light sensor [17].

It is possible to interact with the lens by gesture input, by for example putting your fingers together in order to push a virtual button, by voice command or by gaze tracking. Furthermore the Hololens is Wi-Fi and bluetooth compatible, has speakers built in and brightness and volume control [17].

2.3 Handheld Displays (HHD)

Handheld displays, or HHDs, are hardware that can be used for AR applications. The main characteristics of these devices are that they are handheld, have some display for the user to look at and sensors, both sound and video, in order to gather data from the surroundings. Common for the HHDs is they also run on an operating system which enables developers to add or remove software on them. A personal digital assistant, or PDA, is an example of a HHD. The most common PDAs of today are smartphones, all of which contain video and sound receptors as well as a display [30].

In addition there are more nisched PDAs built with the sole purpose to act as AR HHDs. Some of these do contain the necessary hardware to operate on its own, like cameras and microphones whilst others are connected to this hardware and are then fed the data [30].

2.4 Augmented Reality Softwares

An AR application has to be programmed in order for the hardwares of the system to communicate and work together properly. Creating an application from scratch can be a very tedious process and there are some remedies for this. There are free to use softwares available which reduce the need for creating application engines from scratch, such as Unity. Even though it is a game engine, it can be used to create applications and for a wide variety of operating systems [31]. Unity makes it possible to take advantage of third party software development kits which further reduces the amount of programming needed.

2.4.1 Unity

Unity is a game engine with support for multiple platforms. A game engine is a computer program that offers a game-development framework that does not require extensive programming knowledge in order to create games and applications [31]. Unity is utilized in multiple industries and is not confined to the gaming industry. It offers the possibility of making advanced applications with the use of third party extensions such as Vuforia. Some of the core assets in Unity are more user-friendly but in order to make an AR-application some programming is needed [32]. The primary programming language inside of Unity is C#.

2.4.2 Vuforia

Vuforia is a software development kit that provides the ability of creating AR applications [33]. A software development kit consists of pre-packaged software code that is ready to be implemented in a project. It uses the video feed together with its technology to recognize and track images and 3D-objects in real time. Since Vuforia can track an object's position and orientation in real time, that information can be used in order to project virtual objects onto the video.

2.6 Software system structures

Software system structures are graphical representations of how softwares are structured as well as how their different components interact with one another. Software system structure can also be called system architecture, both of which refers to the design of the program. The system structures are most commonly used in the planning phase of a project and are often represented in different types of flowcharts [34]. There is not a single correct way to create a system structure but they vary from time to time and can be altered to better fit the current project.

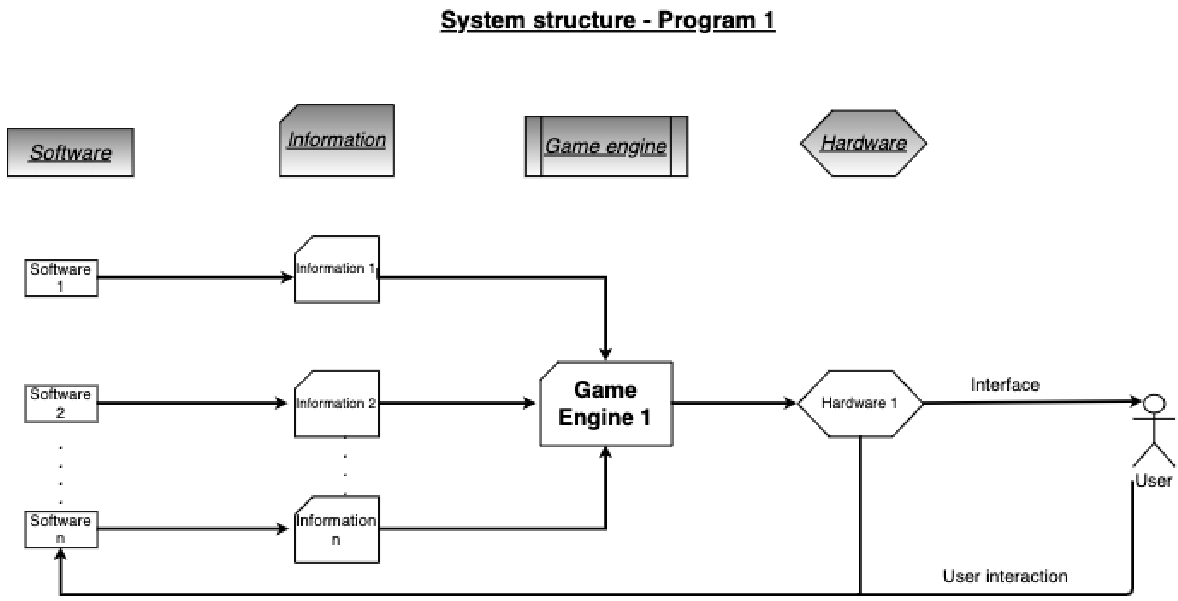

Figure 3. An example of a system structure showing how the different components of the program interact with one another.

The illustration should be detailed enough that a programmer could create the program from the system structure. For example, what information is sent from software 1 to software 2, or as shown in figure 3, software 1 to game engine 1 is important data that system structure consists of. All inputs, outputs and communication within the program, is illustrated. The user interaction is also shown.

If a flowchart is chosen for the system structure all software, hardware, databases, functions, etcetera are usually represented with figures and with different shapes. A software could, for example, be represented by a circle while a database is represented by a square [35]. The way different components interact with one another is usually denoted by different types of arrows accompanied by what interactions are taking place [34].

3 Method

The method chapter aims to show the methodology used to create the demos. The first step is to identify the problems faced by the mining industry and the opportunities for improvement by utilizing AR technology. This is done by a series of interviews with key personnel from different sections of the mining industry. Afterwards, a brainstorming session is arranged to generate potential concepts to be evaluated for further development. Finally, demos of the concepts are created.

3.1 Investigation and problem identification

One key component to finding a possible AR application is identifying a problem to be solved in the mining industry. It is also important to investigate the overall usefulness of the application, since some problems are simply not possible or worthwhile to solve with AR. With the purpose of finding all possible areas of use for an AR application in the mining industry, it is beneficial to study already existing applications. Existing applications can also be used to further improve on or find combinations of multiple applications. To identify what problems can be solved with AR, the ambition is to investigate all parts of the mining industry.

To find relevant quantitative data with regards to different parts of the mining industry some research needs to be done. Official figures on emissions and energy consumption in the mining industry can be determined using publications and results conveyed by government agencies and scientific papers. It is also relevant to do some research about other resources consumed by the mining industry such as funds or water.

3.2 Interviews

The interviews are focused on gathering qualitative data, since it is more useful than quantitative data when trying to find consequences and connections in a system. This is because qualitative data enables an in-depth study.

In order to have a common set of questions but also allow a discussion with each interviewee, semi structured interviews are performed. The advantage of this type of interviews is that the interviewer does not need to follow a formalized set of questions and has the possibility to adapt the questions to the interviewee's area of knowledge or ask further questions about what he/she just said. Open-ended questions are asked allowing the interviewee to give his/her point of view. A set of questions is however set in advance and asked to every interviewee in order to compare the answers of people working in different areas within the mining industry. The interviews each last between 30 and 45 minutes with the exception of one which is conducted via email. The interviews that are done verbally, are recorded and later summarized to specify the key points brought up.

Since the majority of interviewees requested that they and their company would remain anonymous, the different companies are designated with a letter and a number. The letter signifies if they are a supplier (A), a mining company (B) or an academic (C) and the number shows the specific company/institution in the category.
The list of interviewed organizations is as follows:

- A1: a Swedish supplier of mining equipment, represented by a life-cycle optimization engineer/manager
- A2: a Danish supplier of mining equipment, represented by a chief engineer
- A3: a Brazilian developer of AR applications, represented by a sales director
- B1: a Swedish steel producer, represented by a service manager
- B2: a Brazilian mining company, represented by a geologist
- C1: Chalmers University of Technology, represented by an associate professor

From the supplier-side, representatives from two companies are interviewed to gain insight into what perceived needs and demands they experience from the mining industry. One is a life-cycle optimization engineer at company A1, manufacturing equipment for the rock-processing and mining industry. The other one is a chief engineer at company A2 supplying the cement and mining industry. For the AR development itself, a sales director at company A3 is interviewed. The purpose of the interview with A3 is to discover the current direction of the AR development and what general aspirations companies would have for it.

The perspective of the mining and mineral processing industries is represented by two interviews. One is a service manager at Company B1 whose main operation is producing steel from raw materials, and is therefore closely tied to the mining industry. The other is a geologist at company B2, a subsidiary of one of the largest mining companies in Brazil.

Finally, an associate professor at a rock-processing research group at C1 is interviewed to gauge the difference between current research taking place at universities and the actual development in the industry. In addition, this interview gives an outside perspective on the level of technological progress achieved in the industry as a whole.

3.3 Generation and screening of concepts

For the sake of minimizing the risk of missing valuable concepts, as many concepts as possible are produced initially. The concepts are thereafter evaluated and compared in order to find the most valuable ones.

3.3.1 Concept generation

After identifying problems in the mining industry and studying the potential of AR in this field, a list of concepts is generated. In order to get a lot of different ideas that cover several aspects of the industry needs, a brainstorming session is organized. During this session, the whole project group and its supervisor are gathered around a table and write down all the AR applications they can think of on paper. Then the ideas are sorted and rewritten in the form of concepts. Finally, they are categorized by area of application.

3.3.2 Screening of the generated concepts

When the set of possible applications to develop is established by the brainstorming session, a decision matrix is used to determine the most suitable alternative to pursue. This decision making tool is most commonly used when a decision between different options with similar attributes has to be done [36]. In order to compare the generated concepts to each other and determine which one to further develop, some demands are set up. The demands are not requirements but valuing fundamental properties within the concept that will help to determine which concept is the most valuable. They are based on previous theses, personal knowledge and interviews. In addition, consideration is taken to what expectations and purchasing conditions the mining industry may have for different applications.

All the concepts are considered to fulfill the different demands to some extent, but the aim of this method is to find out which one of the concepts fulfills the demands the best. In order to get a qualitative result to stand on, a scoring system is created. All concepts are rated on how much they fulfill the demands relative to each other. The scoring system contains a comparison scale from 1-5. The definition of every number is the following:

1. - Far below average
2. - Below average
3. - Average
4. - Above average
5. - Far above average

All the scores that a concept gets are then summarized to allow them to be evaluated against one another. The concept with the highest total score is considered to be the most valuable one and is chosen to be further developed.

Decision matrices can have a varied structure but it is decided in this project to have the available concepts to choose between running horizontally on the top and the different demands running vertically along the left most side of the matrix, as seen in table 1.

Table 1. An example of a decision matrix. In this scenario, Concept W got the highest score and should be chosen.

	Concept W	Concept X	Concept Y	Concept Z
Demand A	3	2	2	2
Demand B	4	1	3	1
Demand C	5	3	2	3
Demand D	2	4	1	4
Demand E	4	1	1	3
Sum	18	11	9	13

3.4 Making of the demos

The development of the demos begins with the establishment of a system structure to break down the whole system in its key components. After establishing the system structure, all the necessary preconditions have to be met. One precondition is that all the components in the system are present, and that they are able to communicate as expected within it. Compatible hardware enables the possibility of the development of the software. The software used in the demos is Unity in conjunction with Vuforia.

The aim of creating the demos is to showcase a solution to a specific problem in the mining industry and subsequently making an evaluation. The demos are therefore going to be solving problems gathered from the mining industry.

4 Results

In the following chapter the identified problems and insights gained from the thesis are described and listed. Thereafter how concepts were chosen is explained and finally the resulting demos are explained and shown.

4.1 Identified problems within the mining industry

When investigating what challenges the two mining companies are currently facing, both of them emphasize the need for qualified labour during their interviews. When more advanced equipment is introduced, operation and maintenance require new specialized skill sets which are in high demand. The representative of company B1 mentions the possibility of using AR in the form of an education tool as a solution to this.

The issues of planning and logistics are also brought up during the interviews. The company B2 has recently introduced an AR application for scanning and surveying excavation sites. The goal is to expand this usage to obtain real-time information on the soil for better accuracy of the drilling operation and thereby improving the resource efficiency and work-safety. As for company B1, AR is not currently used but during the interview it is suggested as a solution for improving transport logistics and navigation on work sites. This is also mentioned in connection with work safety, for instance, to assist in taking the correct measures during breakdowns which can be complicated. Safety is an aspect worth improving due to the large amount of work injuries in the mining industry as shown in the report by the American National Safety Council [8].

From the interviews with the suppliers, the aforementioned issues with attracting qualified labour gained further credibility. The interviewee from company A1 claims that new mining sites are often set up in more and more remote locations which makes it difficult to have onsite specialists available. In addition, systems that are used in the mining industry have become more advanced and that some workers do not have the necessary competence to operate them. The method of maintenance is at the same time transitioning from a preventative nature to a more predictive one to meet the customers' demands for greater productivity. The other interviewee representing company A2 points out the large costs of halting the production process for maintenance which could be minimized by planning and calculating the service intervals more efficiently. This involves data collection on critical parts of different machinery and analysis on a detailed level which also increases the demand for qualified labour.

The representative of company A3 developing AR-software brings up remote expert assistance among examples of promising AR applications, which could help companies to utilize their current qualified labour more efficiently when hiring more specialists is not possible.

From the outside perspective of the associate professor at C1, the need for communication and information sharing along the production chain is identified. This could, for example, involve real-time information sharing on the working material or downtime. The need for real-time information on machinery for predictive maintenance is also emphasized, which gives an AR application in this area an advantage since it enables the user to have relevant information readily available.

To summarize, several areas in the mining industry are open to improvement which can be accomplished with AR. The identified problems within the areas include logistics, safety, qualified labor and maintenance.

4.2 Concept generation and screening

Based on the identified problems within the mining industry and theory on AR, several concepts were generated and then screened so that the most suitable ones can be taken to further development.

4.2.1 Brainstorming session

The brainstorming session resulted in a lot of ideas that were inspired by concepts from previous theses, existing technologies or the combination of literature, personal knowledge and creativity. At the end of the session, ten concepts were identified and grouped together with other concepts that belong to the same area of application. Six categories could then be identified: safety, overview, maintenance, training/education, support, and planning. A brief description of all the generated concepts can be seen in table 2.

Table 2. The ten generated concepts listed with their respective category, subcategory as well as a short description of the concept.

Category	Subcategory	Concept	Short description
Safety		Geofencing	Monitoring working conditions, air quality, etc. or guidance for rock blasting.
Overview	On site	Visualize "flow data"	For example the output for every machine or how different material moves through the process.
	Off site	Remote process observation	See the mining area as a large 3D model with real-time data for various vehicles / machines in place. The real-time data can be position, direction, environmental emissions etc.
Maintenance	Online	Remote expert help	The expert can see what the operator sees and guides through live video. Examples of how to guide: talk, highlight areas in the operator's AR glasses, etc.
	Offline	Troubleshooting Help	A "drawing of how things should look" is projected to help technicians find irregularities faster.
Training		Assembly instructions	A 3D model is created in CAD for each step of the assembly. The operator can switch between the steps using virtual buttons.
Support		Checklists on-site	Project an interactive checklist with different tasks.
		Support for operations with limited access/visibility	Provide visibility where sight is limited. For example behind obstacles.
Planning		Geometric dimensions	Guide the planning and placement of machines/materials.

4.2.2 Concept screening

After the brainstorming session all project members sat down together and worked on a decision matrix, as can be seen in appendix A. The basic idea of the decision matrix was to be a guide for choosing concepts for further work. All concepts are presented in one column with eleven demands to be scored as the rows. As mentioned in 3.3.2, the demands are not requirements but fundamental properties within the concept based on previous theses, personal knowledge and interviews. The eleven demands were:

- Interest from industry
- Complexity in hardware
- Complexity in software
- General complexity
- AR usefulness compared to screens
- Total cost
- Contributing to more sustainable resourcing
- Contributing to better working conditions
- Contributing to effectivity/productivity
- Increasing skills for workers
- Flexibility (applicability to other areas)

Furthermore, a brief comment with motivation about how well a concept fulfills the demands is included in the matrix, see appendix A. A final summarized score for each concept can also be found in the bottom of the matrix. The five concepts with the highest score are further analyzed. After discussions within the group the decision to continue working with the three concepts with the highest score was made, see table 3.

Table 3. Short summary of the decision matrix. The chosen concepts are colored green and the rest are red.

Category	Subcategory	Concept	Total score (11-50)
Safety		Geofencing	32
Overview	On site	Visualize "flow data"	26
	Off site	Remote process observation	18
Maintenance	Online	Remote expert help	37
	Offline	Troubleshooting Help	34
Training		Assembly instructions	39
Support		Checklists on-site	38
		Support for operations with limited access/visibility	34
Planning		Geometric dimensions	29

4.3 Chosen concepts

After rating and screening the generated concepts, the aim was to create a demo for each of the three chosen concepts, which were assembly instructions, checklist and remote expert assistance. They are described in detail below.

4.3.1 Assembly instructions

The concept “Assembly Instructions” originates from a concept image in the bachelor's thesis at Aachen university 2019 [9]. The core functionality of the concept is to guide an operator through the assembly process while leaving both their hands free to use. These instructions consist of letting virtual copies of the parts be assembled step by step inside the application so that the user can imitate the steps in real life. These steps can then be scrolled through back and forth, giving the user the possibility to choose which stage of the assembly process to be aided with.

As shown in the system structure in figure 4, three different softwares and one game engine is included in the system. The 3D-models in this demo are CAD-models made with Autodesk Fusion 360. In order for Unity to display these parts, they need to be exported to a .obj-file format, a feature already built into Fusion 360, see figure 5. Some guiding arrows are also modelled to help make the instructions as clear as possible.

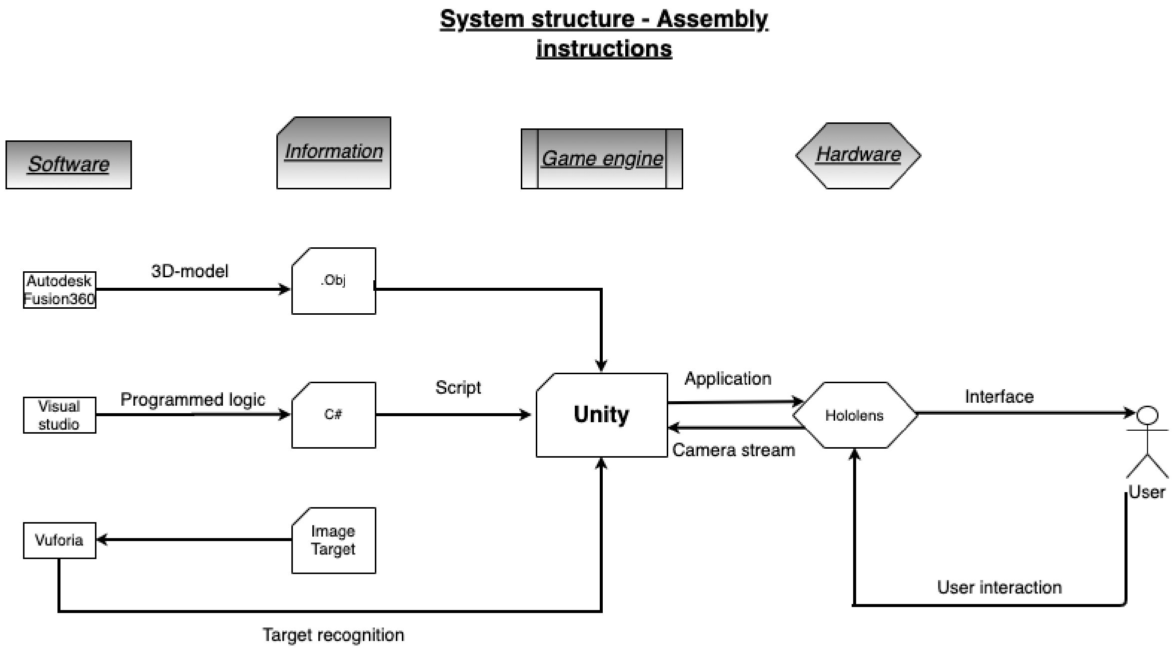

Figure 4. Assembly instructions’ system structure. Describing the data flow and interactions between the components.

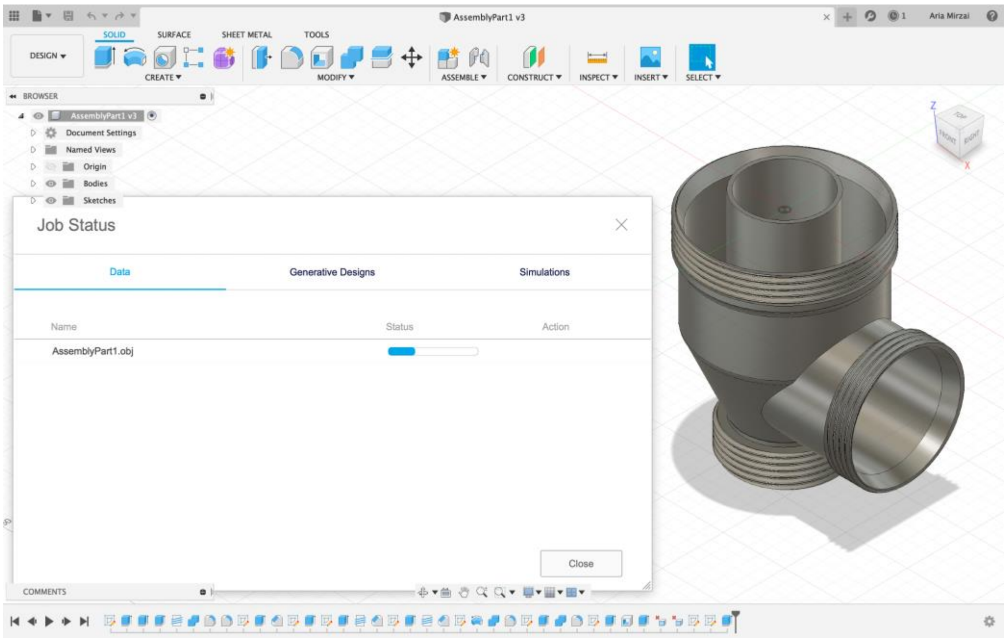

Figure 5. CAD-model being exported into .obj-file format.

The parts being assembled virtually are observed by users through the application in their Hololens headset. The interface then contains buttons that enable the user to toggle through the steps of the process. The buttons and guiding animations can be created directly in the Unity game engine, while the logic behind them needs to be coded in Visual Studio with the programming language C++. From there a script-file containing the code can be imported back into Unity. The important task for the code is to keep track of which step of the assembly the user is on, and activate/deactivate models and animations accordingly.

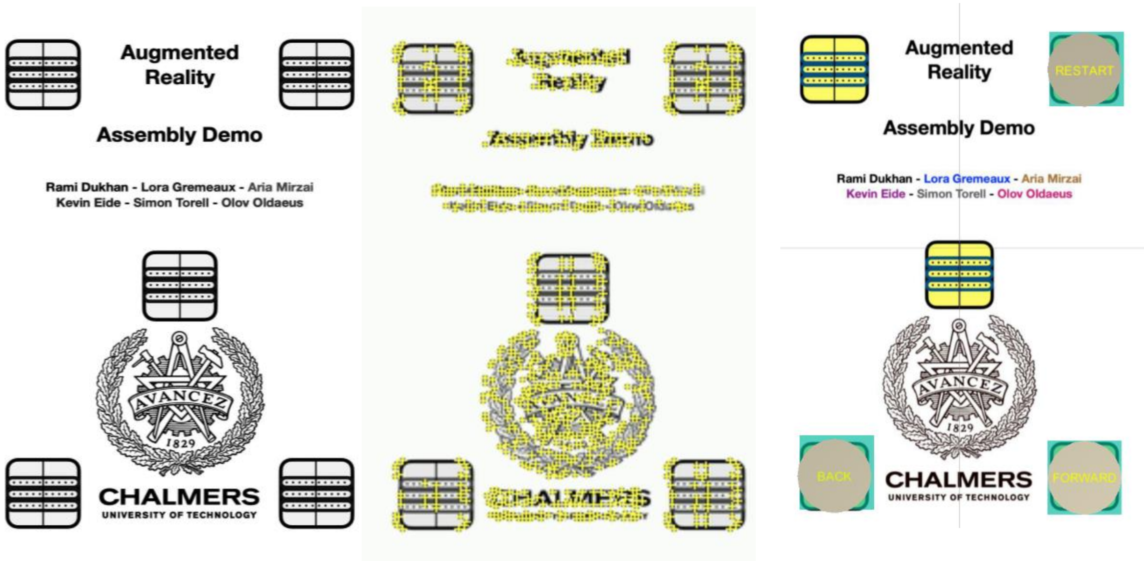

Figure 6. On the left is the original image target, in the middle is Vuforia detecting the high contrast points and on the right the virtual buttons are projected.

An image has also been pre-selected for the application to display the demo on as can be seen in figure 6. Since this image target is put into Unity through Vuforia's software, high contrast points have already been located which is what allows the application to recognise it automatically through the hardware's camera. Ideally, all models and buttons should be placed upon these high contrast points to ensure that everything is at its intended position and that the application correctly recognises when a user is trying to interact with a button.

4.3.2 Checklist

The concept "Checklist" stems from the brainstorming session. The core functionality of the concept is displaying a user guide hands free for the user. The user guide consists of a set of tasks for the user, who is then able to mark tasks as completed and to see which ones are left.

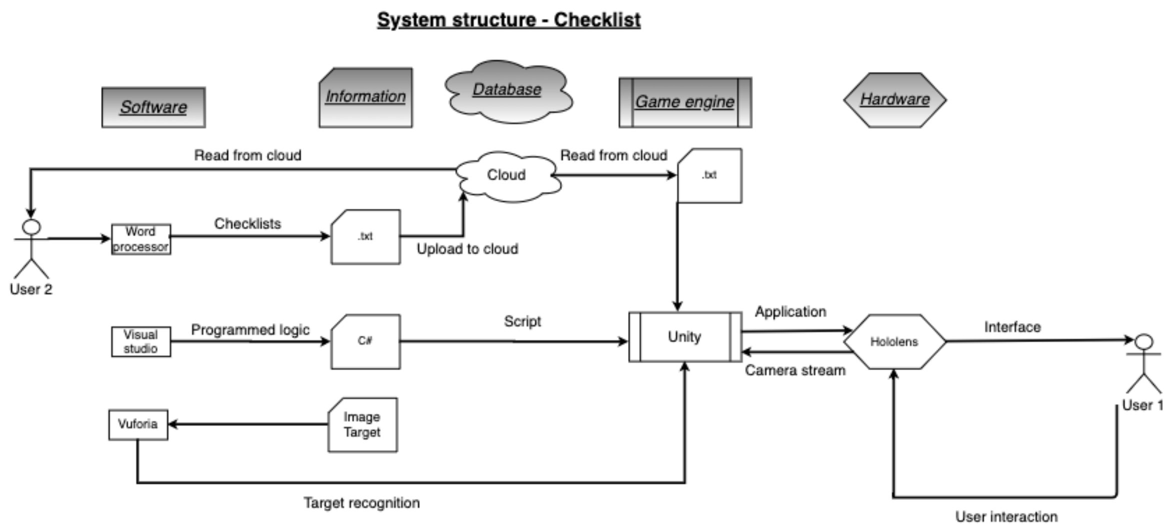

Figure 7. Checklists system structure. Describing the data flow and interactions between the components.

The system structure is illustrated in figure 7. The application requires two user inputs, one provides the information which is to be displayed in the checklist, the other is the user interaction. User 2 uploads checklists in .txt-format to a cloud that Unity has access to. The application is programmed to read the uploaded .txt-file from the cloud and project the checklist in the user's field of view. It is also programmed to have buttons that can tick off instructions in the checklist, adjust the orientation and size and replace it with another one. The buttons are projected onto the image target as seen in figure 6. The application, including all features, is programmed in Visual studio with C# as the programming language. The hardware used in the system is a hololens that projects the list and also allows users to interact with the system and its interface through the constant camera stream into Vuforia.

4.3.3 Remote expert assistance

The concept "Remote expert assistance" stems from the interview with the representative from company A3 who is working with AR applications for multiple industries. The core functionality of the concept is user guidance via video communication between an expert and a user with inadequate competence.

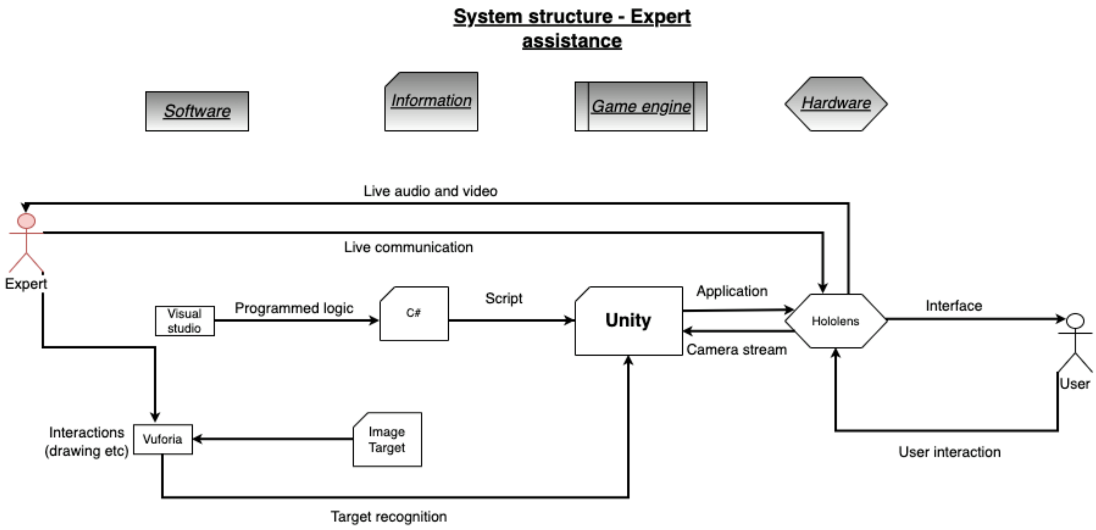

Figure 8. Expert assistance system structure. Describing the data flow and interactions between the components.

The system structure is illustrated in Figure 8. The application operates by exchanging an audio- and video feed between the user and the expert. This enables the expert to guide the user, either via verbal communication or by drawing in the users field of view. The expert can therefore instruct the user remotely, which is applicable both in training of new workers and during on-site operations.

4.4 Demos

In this chapter it is described what problem the application aims to solve and to show in detail how the application operates. Thereafter, the demos are presented using pictures of what the end user will see as well as some comparisons between the real world and the AR.

4.4.1 Assembly instructions

As mentioned in 4.1 there is a shortage of qualified labour as well as the machinery becoming more advanced. This application aims to remedy this by alleviating the need for additional training of the operators by making the assembly more accessible. The risk of operator errors during assembly is simultaneously reduced, thereby increasing work safety.

To begin the demo, the operator simply needs to look at the predetermined image-target through the Hololens with the application installed. The demo then starts by showing the first of the objects to be assembled along with three virtual buttons; “forward”, “back“ and “restart” for toggling through all assembly steps as seen in figure 9.

Figure 9. On the left the initial step shown in the application displaying the first object to be assembled. On the right is the second assembly step. This step is shown once the "forward" button has been pressed once.

For each step in the assembly, animations and floating arrows give a clear guidance to the user on how the parts should be put together, up until the final step is shown. Since all models are rendered fully in 3D, they can be viewed in all angles by changing the position of the chosen device. The models displayed in figure 9 are place holders for machine elements that an operator would work with in the mining industry.

The following figure 10 shows an image series of the next steps in the assembly of the models with the application running on a mobile phone:

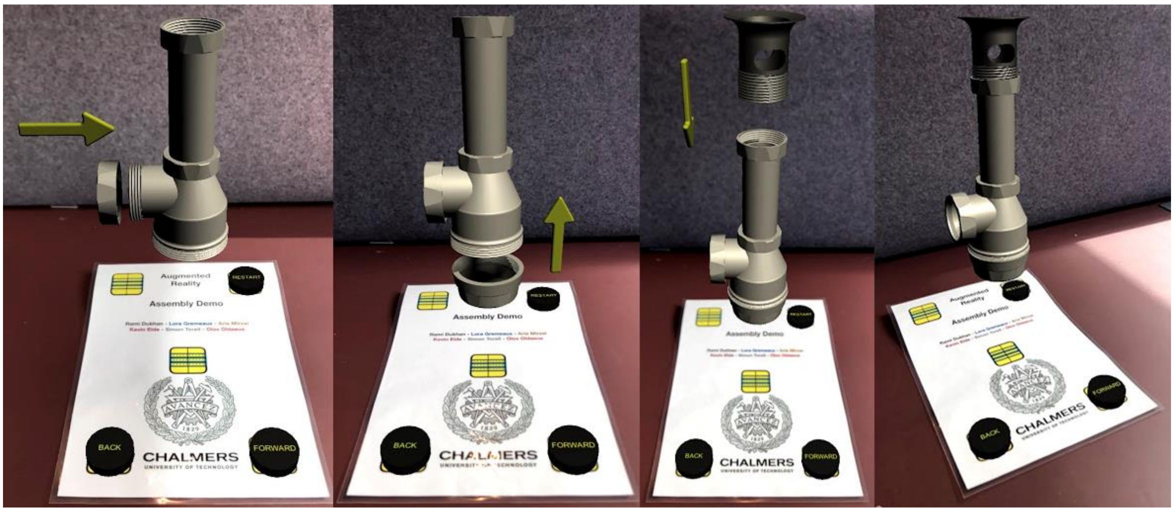

Figure 10. Illustration of the assembly process from left to right.

Figure 11 shows the same application running on a Microsoft Hololens. The visual appearance here changes due to the Hololens turning the models slightly transparent. The screen technology of this first generation Hololens is also not able to provide us with a brighter image. In addition, the area in which the application is shown as well as where the image target is recognized, is limited, in comparison to the user's field of view.

Figure 11. The application, seen through Microsoft Hololens.

By also having physical versions of the components the demo participants were able perform the assembly by following the instructions, see figure 12. The tests showed that the application could successfully be utilized when assembling the object.

Figure 12. An operator using the application through the Microsoft Hololens while assembling the physical model.

4.4.2 Checklist

One challenging aspect that is emphasized during the interviews is work safety. This is further supported by the report published by the American National Safety Council [8]. This application strives to reduce the possibility for human error by providing the operators with checklists in their field of view. These lists can be designed after safety protocols already established by the company using the application.

The Checklist demo begins with the user looking at a predetermined image target that displays two virtual buttons. One button prompts the user for a selection of a list. The other button starts the actual checklist application, see figure 13.

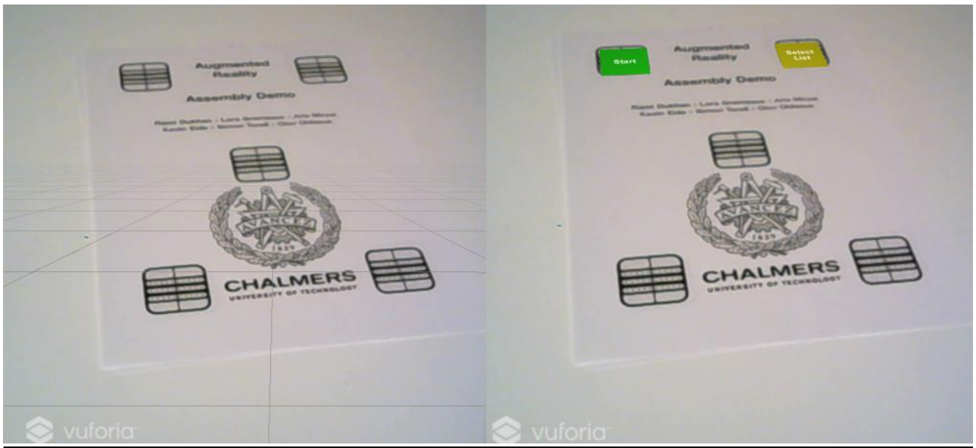

Figure 13. On the left is the camera view, to the right is what the user sees. The yellow button prompts the user for a selection of a list and the green button opens the list.

The checklist is presented in the form of an AR user interface, as is illustrated in figure 14, meaning that the list is present in the user's field of view. The checklist consists of a set of tasks to be fulfilled associated with the job at hand.

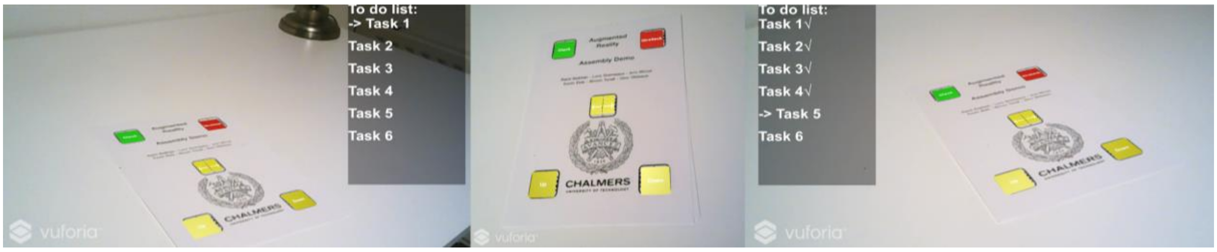

Figure 14. The view of the operator. The operator is able to check the tasks, as displayed on the right, adjust the position and move through the list with the help of the buttons displayed on the image target.

As is displayed to the right in figure 14, the user is able to scroll through the list and tick off completed tasks. The checklist can also be manipulated in terms of position to suit the user’s personal preference.

4.4.3 Remote expert assistance

All of the problems mentioned in 4.1 can be alleviated using remote expert assistance. The issues regarding logistics and qualified labor are mitigated by reducing the number of experts on site, by allowing the expert to communicate visually with workers on multiple remote sites. This also increases the work safety by helping the workers do the job correctly, which can also be implemented during maintenance.

Because of the difficulty of creating a demo of this concept the project group opted to describe how the demo would work rather than creating it in its whole. The difficulty stems in the need of softwares that enable the video-feed as well as the experts ability to alter the video which would have required additional programming. The project group reckons that this would have exceeded the limits on both time and resources available.

The demo works mainly through verbal communication in synergy with the live video-feed. What differs the concept from just a live video communication is the expert's ability to draw and highlight certain points of interest, while talking the user through the critical steps, see figure 15. Since there is no need for communication via text, the need for bulky and obstructive user interfaces disappears.

Figure 15. The view of the operator using the remote expert assistance concept. The written arrows, numbers and other scribbles are done by the expert in real time to give the operator visual cues together with verbal instructions.

5 Discussion

In the following chapter it is discussed whether possible uses for AR technology for the mining industry that can be utilized for improving its operations have been found. Furthermore, the chapter discusses the hardware and its limitations, the methodology used and how the technology could potentially be used in other industries.

5.1 Purpose fulfillment

The corona-pandemic did definitely put some pressure on this project. During the last half of the project almost all communication within the group and with the mentor were done virtually. This made it harder to cooperate during the development of the demos, and caused delays in obtaining resources as CAD-models and access to the Microsoft Hololens.

Still, two demos were completed and the project group feels satisfied with the results. Nonetheless, it would have been beneficial to at least start the development of the "remote expert assistance" demo, but even in perfect conditions, completing all three demos seems to be unachievable within the given time frame.

A possible improvement to the demos could have been to explore the possibilities of not being as reliant on image-targets. Image-targets puts an obvious constraint on the demos, which is that they do not work without them. It would be more flexible for both the demos if everything needed to run them was inside the actual application. This does however require adding some advanced technologies. As an example, to do this with the assembly demo the application would have to itself recognise a surface to put the demo on. And in the checklist-demo, it would not be able to rely on virtual buttons, but rather possibilities such as utilizing hand gesture recognition would need to be explored.

To tie the demos closer to the mining industry specifically, CAD-models of parts from machinery actually present in the mining process could have been used in the assembly demo. This would have given a more accurate representation of the application in use. But due to the difficulty already experienced in acquiring substitute models, getting hold of real part models would not be an efficient use of the time and resources available.

To return to the purpose of this thesis, the results indicate that the applications developed could provide solutions to some of the challenges within the mining industry, primarily the training of the workforce. This problem is emphasized in the interviews because of the difficulty in finding qualified labour for mines residing in very remote locations. Improved training and support for workers could also decrease the risk of operator errors and thus improving work safety. As revealed by the interviews, improvements in this aspect of sustainability are in demand by the industry.

5.2 Hardware

One of the primary benefits of using the Hololens is that it keeps the operator's hands free, while a mobile phone would either have to be carried with one hand or placed in a fixed position. However some unpredicted downsides did emerge when the assembly demo was tested on the Hololens. Mainly the area where the application could be seen was small, forcing the user to stand several meters away from the image-target in order to see all rendered objects. The small display area also resulted in more head movement. If the operator wanted to look at the instructions while navigating the assembly steps, all buttons would not be in the field of view. Other downsides worth considering were the low brightness of the Hololenses screen, as well as users mentioning discomfort with the headset after only brief minutes of usage, such as feeling a lot of weight being put on the nose.

It’s hard to determine exactly how much of the issues with the Hololens can be blamed on it being a first generation hardware. After all, Microsoft is clear with the fact that they are not targeting this product for regular consumers as of yet, but rather as a research tool for companies and universities. Smartphones however directed towards regular consumers to buy. Therefore they might be better suited for introducing AR applications like the ones developed in this thesis to the mining industry, at least until products like the Hololens have evolved to a point where they are not only being considered as a research tool.

Not only would phones be cheaper, but the applications are also easier to use with them. As just mentioned, the small field of view of the Hololens meant a lot of head movement for the user. This is not the case with the mobile phone, since the field of view is only limited by the one of its camera, which as of now is bigger.

5.3 Methodology

The qualitative interviews worked out well for the purpose of the thesis. Due to the fact that there were no requirements for the problems to be identified, only that a real problem was identified, these sort of interviews helped to quickly and efficiently find problems. The fact that only a limited number of people from just a few areas of the mining industry were interviewed did not matter when following the aforementioned reasoning. However due to only interviewing this selection of individuals, identifying some problems that AR could have efficiently solved might have been missed.

The generation process used was sufficient. The brainstorming session did generate a lot of concepts that then could be pursued. Again, the reason this process worked was due to the fact that there were not really any constraints or demands on what application to develop. In terms of the screening process it was again sufficient. The scores assigned to each concept were relative to one another and therefore the resulting score was representative. Furthermore some of the demands that were evaluated were related to the difficulty of executing the project and therefore had to be scored subjectively. Therefore this method performed well. One shortcoming due to the subjective nature of this method is that the thesis group could have interpreted the statements of the interviewees differently than what they meant. Additionally some factors were difficult to score due to the thesis group lacking knowledge within certain areas. For example it was difficult to determine the actual difficulty of a concept due to the groups lacking knowledge working with AR applications.

One thing that would have aided with improving the final applications, as well as gained more insight to the applicability of the software, would have been to have more testers use the application. Especially to have actual operators with experience working in the mining industry would have helped to further evaluate the potential of the technology.

5.4 Other use cases

The applications have use cases that go beyond the mining industry. The assembly demo could be used in any situation where guidance is needed to put something together. If a customer has bought some new furniture in a local store, the seller could technically just provide an image-target such as for example a QR-code containing a demo of how it should be assembled.

The checklist could be part of a wide range of tools provided in a future where AR headsets go mainstream. If future operators are all going to be wearing headsets for help in their work, the checklist feels like a natural part of that interface.

The remote expert assistance, which was not developed in this report, could be a central part of further improving humans ability to cooperate with each other no matter where they are in the world. It has the potential to take the most similar method of doing so, which is through video conferences, to the next level where a person from the other side of the world can see what the user sees through an AR-headset and interact with the environment without being there.

6 Conclusion

The purpose of this thesis was to find AR implementations in the mining industry that brings value. In order to accomplish this, some problems within the industry that could be solved using AR had to be identified. A close communication with the industry was kept to find possible and worthwhile areas to improve. Some problems might be solved more efficiently using other technologies than AR and the goal was to maximize AR's potential while also making the mining operations more efficient.

It is unknown whether the concepts would improve the mining operations since they have not been tested in the field. Following the discussion, it can be concluded that the purpose has been fulfilled. Four areas within the industry that are in need of improvement are logistics, safety, qualified labor and maintenance. The three concepts that were created cover these areas well. Judging by the interview comments, an acute issue within the industry is getting qualified labor to remote locations. All three concepts aim to alleviate this by providing operators with ample and more detailed guidance.

Assembly instructions provide the operators with guidance through all steps during maintenance meaning that even inexperienced workers can perform the maintenance. Checklists supply the users with extra reminders of both safety protocols as well as guidance working in the mine, which could be argued, leads to increased work safety. Remote expert assistance brings a lot of value since it allows for experts to work at multiple remote locations without having to be present physically. It also helps train inexperienced workers to further improve their ability.

The applications developed in this thesis are not flawless and all have room for improvement. So do some of the concepts the project group deemed to be too difficult to attempt. Investigating into using other hardware is also worthwhile since the hololens has been somewhat outdated compared to its competitors since its release.

6.1 Further work

It could be interesting to run the application on the second generation of Hololens. As mentioned in the discussion, the small field of view on the earlier versions of the Hololens could be problematic while working in mines due to a lot of head movement for the user. If Microsoft has improved the view for the user on Hololens 2, it would most likely be advantageous for the user. It could also be interesting to investigate other optional hardware on the market for optimal usage in general or specific for the created applications.

This thesis did not evaluate how intuitive or easy the demos are to use in practice. Neither did it investigate how descriptive the instructions are in the assembly demo. It would be rewarding to let additional persons assemble a product with the applications as guidance and note potential obscurities in the instructions. Then the demo could be further developed and more user friendly. It would also be interesting to research how all three demos work in a real environment.

Since the CAD-models of used machines in the mining industry were inaccessible simpler models of a drain were created and used in the demo for assembly instructions. To make the demo more useful and implementable, CAD-models of a machine in the industry can be used.

The expert assistance demo was never created, due to limited time and its complexity. This work finished the concept itself with system structure, however, a final programmed demo was not created. The final steps in the creation of the demo with the report as the standing point could be additional work.

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Attachments

Appendix A

Decision Matrix / Category	Safety	Overview		Maintenance		Training	Support		Planning
Demand / *Subcategory*		On site	Off site	Online	Offline				
Name	Geofencing	Visualize "flow data"	Remote process observation	Remote expert help	Troubleshooting Help	Assembly instructions	Checklists on-site	Support for operations with	Geometric dimensions
Interest from industry:	2 Indirect interest, not mentioned, but geofencing can fulfill other interests.	3 Have been named in one interview.	2	5 From interviews: difficult to get quilified workers due to mines in remote locations.	4 Maintenance is often mentioned and that short stops in production cost a lot.	4	2 Mentioned in different articles.	4	2 Mentioned in one of the articles.
Complexity in hardware:	4 Different, depending on where to apply the application. HMD or handheld unit.	4 Most likely glasses, hololens for instance. Maybe hand held unit.	2 Detailed drones images to create model of large areas.	3 AR glasses for operator's hands be kept free. The glasses need one independent internet connection and camera.	4 AR glasses to keep the operator's hands free. Do not need constant internet connection.	4 Hardware that allows operator to work hands free.	4 HMD unit that projects AR.	2 3D scanners, because it is the 3D model of a hidden object such as will appear.	3 Any device that can project AR + 3D-scanner
Complexity in software:	3 Software for projection of dangerous areas.	2 Data from machines are needed, maybe install sensors?	1 Location system: to find out where the objects are in the mine.Continous updated. Any device can be used.	2 Stream videofrom the glasses & receive/project video from the expert. Expert able to write in the operator's view.	3 A software to project how the machines should look like.	4 CAD software that can export formats compatible with Unity. Animations, eg show how the parts should sit together.	5 Software that project a list which the user can change.	3	2 Software for projecting scanned machines. Possible software for calculating grid and height differences.
Complexity:	3 Average	1 Difficult	1 Difficult	3 Average	3 Average	5 Easy	5 Easy	2 Pretty hard	3 Average
AR usefulness compared to screens:	2 Hard to determine	2 Doubtful, work very well on screens. But, It can be used as a tool for a fast overview for people working at fields.	1 Doubtful.	4 Advantageous since both operator and expert share the same field of view.	3 Faster troubleshooting.	3 The operator can focus on only the work step with his hands free	1	5 Depending on task, it's not allways possible to present on 2D-screen.	4 More fair view to see it on site.
Total cost:	4 Low.	4 Not very high. Scanners/sensors + data are necessary.	2 Depending on how hard it is to create the location system.	2 Expensive. Need advanced AR glasses. The expert also need a software to be able to interact with the opperator.	4 Cheap	4 Cheap	4 Cheap	2	4 Not very high. Something to project with. Bit more expensive due to data need.
Contributing to more sustainable resourcing:	1	2 Low - average. Used in planning of service and flows, or locate bottlenecks early in the process.	2	4 Saves a lot of time and resources.	3	3 Resource-efficient because the operators educate themselves.	2	3 Saves time and may make it possible to solve certain tasks for a lower cost (eg service)	3 Possibly better resource management in terms of time.
Contributing to better working conditions:	5 A lot, the main purpose with the concept.	1	1	3	2	2	4 Potentially, easier to ensure that all steps and processes are started correctly.	4 Reduces faulty possibilities	1
Contributing to effectivity/productivity:	1	4 Same as above, planning and finding errors/bottlenecks.	4 Maybe in planning purpose.	3 Faster training and service.	3 Shorter maintenance / repairs. Provides more up time.	3 Potentially faster learning.	3 Faster start-up of processes and operations.	4	3
Increasing skills for workers:	2 Can be used to educate workers about danger.	1	1	4	3	4 Could be a possible way to educate workers.	3 Not really, but it reduces things workers need to remember.	2	2
Flexibility:	5	2	1	4	2	3	5	3	2
Σ (11-50):	**32**	**26**	**18**	**37**	**34**	**39**	**38**	**34**	**29**
Ranking:	5	-	-	3	4	1	2	4	-
Continue to work with:	No	No	No	Yes	No	Yes	Yes	No	No

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