State of the Art and Future Perspectives of Industrial Augmented Reality

Application in Smart Manufacturing

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Abstract

Augmented Reality (AR) is one of the technologies of Industry 4.0 that can contribute significantly to smart manufacturing processes by increasing performance efficiency. AR started its development path last century and has already been integrated into the manufacturing industry. Yet there are still a lot of challenges that prevent it from being massively used. To understand how this technology should be enhanced further to achieve a successful future, it is important to gain a comprehensive overview of this advanced technology to define its strengths and weaknesses, and what issues should be addressed. Concerning the above-mentioned issue, it was decided to screen possible pathways of how AR can contribute to the manufacturing processes in the future. To achieve this goal the current state of the technology was examined, as well as its challenges and future perspectives from the point of view of the current AR and manufacturing experts in comparison to the future talents were discovered.

As for the implementation methodology, the triangulation method was applied. Thus, both quantitative and qualitative data were collected and analyzed. Interviews with 6 experts in the sphere of AR and/or manufacturing were conducted. Moreover, a survey with 86 students was run.

The information gained from the analysis of primary and secondary data allowed us to review and realize the current condition of AR development and exploitation. It was revealed that the extent of AR device utilization is lower than expected, and it still stays at the piloting stage. It is due to the existence of a considerable number of problems on the technical and organizational sides. Addressing these issues would boost AR deployment considerably. In general, it is believed by current experts that in 3-10 years most of the difficulties will be solved and it would be possible to apply Augmented Reality systems in manufacturing processes with maximum efficiency, however, future talents are still doubtful about the further development of the technology.

Keywords/tags

Augmented reality, smart manufacturing, industry 4.0

Miscellaneous

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Contents

Figures

Tables

List of abbreviations

AR = Augmented Reality

AI = Artificial Intelligence

IoT = Internet of Things

VR = Virtual Reality

IAR = Industrial Augmented Reality

CPPS = Cyber-Physical Production Systems

MR = Mixed Reality

RV continuum = Reality-Virtuality Continuum

CAD = Computer-Aided Design

CCD = Charge-Coupled Device

HMD = Head-Mounted Display

HHD = Handheld Device

FOV = Field of View

HSE – Health, Safety and Environment

HMI = Human Machine Interface

HCI = Human-Computer Interface

HRC = Human-Robot Collaboration

DT = Digital Twin

XR = Extended Reality

1 Introduction

The emergence and development of technologies have become an integral part of people's lives. The world has faced four industrial revolutions. There have been an big number of new technologies opened to the world and new possibilities alongside. The fourth industrial revolution, which is taking place now, has already brought a lot of beneficial advances and continues to produce new solutions to this day. Both everyday life of people and business world gain advantages from it.

All the technological advancements have caused positive changes in the field of industrial development. The concepts of Industry 4.0 and Smart Manufacturing appeared. Businesses started to think about how it is possible to enhance the process of product production with the help of new technologies, and by doing so, get a competitive advantage and higher profit.

However, a lot of companies are still oblivious to the big number of opportunities that cutting-edge technologies can provide. Such a situation applies to the technology of Augmented Reality (AR). Smart manufacturing is predominantly associated with such technologies as AI, IoT, Cloud computing, Cognitive computing, or VR, and AR is most of the time left aside. By ignoring this technology, companies miss the chance to make a profitable long-term investment that can improve manufacturing processes, and therefore lead to savings of time, money, and resources. However, there are still a lot of challenges that prevent AR technology to integrate into the manufacturing processes. The AR systems themselves are technically and ergonomically still not perfect and require a lot of enhancements. Moreover, the implementation of AR requires short-term changes at different organizational levels, and most of the companies are not ready to make them and alter their traditional ways of working. Lack of success stories and examples of the technology application and its benefits is another reason that stops them from investment.

Therefore, in order to facilitate the integration of Augmented Reality devices into the manufacturing industry for it to gain its advantages, there is a need of examining and reporting the current state of the technology development, including use cases and existing problems that should be started to be solved. Afterward, future perspectives should be realized so that the understanding of development directions and possibilities is considered.

1.1 General importance and motivation

Investment in emerging technologies and their adoption in enterprises grows considerably. A noticeable AR development and its penetration into the market can be seen in the last few years. The rise of this technology promises a lot of new opportunities for many industries. According to Gartner's (2021) Emerging Technologies and Trends Impact Radar, AR Cloud is going to be massively used in 6-8 years and will be one of the main drivers of the business world (5 Impactful Emerging Technologies for 2022). Companies should invest their time and money into examining the opportunities of AR and integrating it into their processes already now to be prepared for the future and get ahead of their competitors.

Another reason that makes consideration and examination of AR application in manufacturing crucial is that there is a lack of knowledge among companies about the benefits that the technology can bring to them and a lack of real-life successful examples of this technology being applied. Hence, there is a gap between theoretical knowledge and practical applications. At the current moment, there are mostly pilot projects of AR usage in manufacturing and only a few examples of its deployment and utilization inside of the companies. There is an urgent need for demonstrating benefits of AR by connecting the accumulated knowledge base of the IT world with the companies' one, revealing the main issues preventing AR from fast and successful integration, solving them, and understanding possible future ways of technology development and its contribution to manufacturing.

All the above-mentioned big-scale aspects regarding the importance of the study of the current topic aroused the author's motivation to research the field of AR in manufacturing more deeply. However, there was also a personal interest in examining this theme: having work experience at the car manufacturing factory and being a witness to its processes, raised concerns and thoughts about how they can be improved. Later the author found out about the existence of this technology and its usage in manufacturing and was interested to know how it can change and facilitate conventional processes. Thus, there is a strong motivation to get more understanding of AR, its challenges, and future development.

1.2 Research objectives and questions

AR cross-sectional integration is forecasted to boom in the next years (Perkins Coie LLP et al., 2020, p. 3). Therefore, there is a crucial need of tracking the current development of AR technology and the future possibilities that it can provide for manufacturing companies. That is why the objective of this research is:

- to screen potential pathways of how IAR can contribute to smart manufacturing in the future from its current state as practiced by manufacturing firms.

In order to fulfill this objective, it is crucial to raise and answer particular research questions which can lead to a logical conclusion. There are three main research questions to be answered:

1. How is AR currently used in processes of smart manufacturing?
2. What are the current challenges that hinder the adoption of AR in smart manufacturing?
3. What are the future perspectives of AR development in the manufacturing industry as seen by current AI and manufacturing experts in comparison to the future talents?

1.3 Thesis structure

Thesis should follow a logical structure so that the information presented was easy to perceive and understand. This research starts with a dictionary of abbreviations for a reader to gain realization of what the author talks about and to always have a possibility to come back and check the meaning if one forgot. Afterward, there is an introduction that makes a reader familiar with the topic and stresses its relevance. It also covers the research objective and questions that are to be answered in the further parts. Then a critical analysis of the literature review follows. Already existing knowledge base is presented there. In this chapter, one can learn the history of AR, its main components and processes, state-of-the-art use cases, challenges of the technology integration as well as future perspectives. Thereafter, methodology and implementation chapter is revealed. It represents the most significant information for the research process for the author to comply with and follow and for the reader to realize how the research was run. The chapter includes research design, sample, the ways and methods of data collection and interpretation, and the plan for the quality and ethics of research. Chapter 4 is devoted to the examination of collected primary data (interviews, survey, and personal observation) and drawn conclusions from it. Finally, discussions and conclusions take place. In this chapter the research questions are answered. Moreover, theoretical and practical implications of the work are provided, and its process and results quality are evaluated. Lastly, limitations of the current research and its possible future implications are exposed.

2 Literature Review

A literature review can be defined as a comprehensive summary and critical analysis of works that have been already written. It not only helps to gain knowledge about the topic but also to reveal possibilities for one's research and refine its questions and objectives (Saunders et al., 2012). Figure 1 below demonstrates graphically a structure of the literature review of the current work. The knowledge base is represented in a logical order and covers firstly wider topics and then narrows down to more specific subjects. The first subchapter focuses on the definition of Industry 4.0 and Smart Manufacturing in general to understand the 'environment', to which research is applied. The next two chapters are concentrated on AR and IAR, their history and comprehension of way of their functioning. Section 2.4 refers to relevant real-life examples of AR practical applications in different areas of smart manufacturing. Afterward, we cover the main challenges and future perspectives of IAR development in the next two subchapters. Finally, all theoretical base is summarized in the last subchapter.

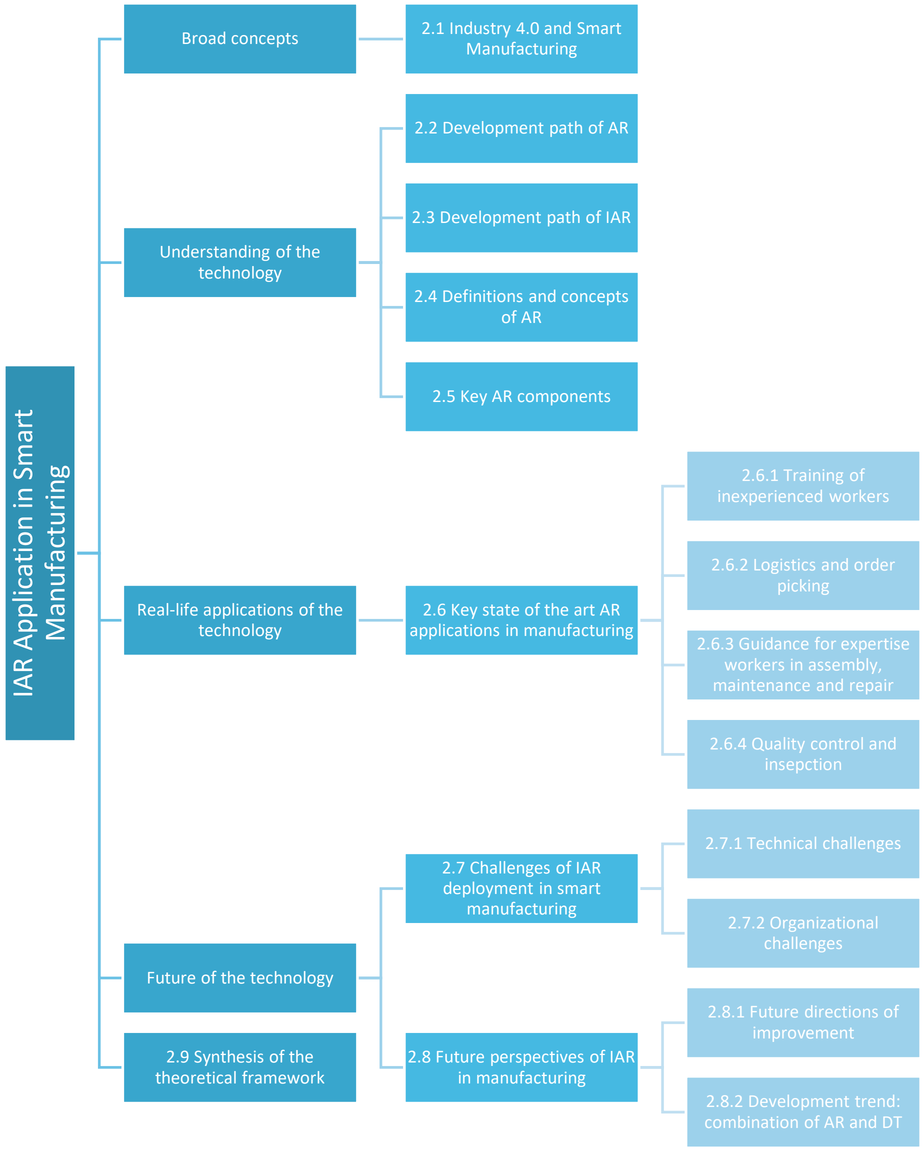

Figure 1. Literature review overview

2.1 Industry 4.0 and Smart Manufacturing

The world has overcome three industrial revolutions, each of which has brought new advancements, challenges, and opportunities. The fourth industrial revolution, which has also another name ‘Industry 4.0’, had its roots in the program, which was initiated by German authorities with educational institutions and private companies and aimed at enhancing German industry with the help of advanced systems of production (Frank et al., 2019, pp. 3-4). The focus of Industry 4.0 is to provide the connection between the two worlds: a physical and a digital one. The provision of such a connection is regarded as a cyber-physical production system (CPPS). With its help, manufacturing can become more intelligent, flexible, efficient, and consequently profitable (Egger, 2019, p. 3).

Although smart manufacturing lies at the core of the fourth industrial revolution, it was framed earlier. Manufacturing processes have been evolving, new technologies have been appearing, and hence the definitions of advanced manufacturing systems have been also changing with time, but the concept behind them has always remained similar. For example, the National Institute of Standards and Technology (NIST) (2022, description) defines smart manufacturing as 'a fully integrated, collaborative manufacturing system that responds in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.'

It is possible to gain some insight into smart manufacturing with the help of a graphical representation provided below (see Figure 2). It reveals some characteristics and technologies related to this concept, encompassing the results of the work of Mittal et al. (2017), which focuses on the collection and structurization of concepts and advancements closely connected with smart manufacturing (pp. 1352-1353).

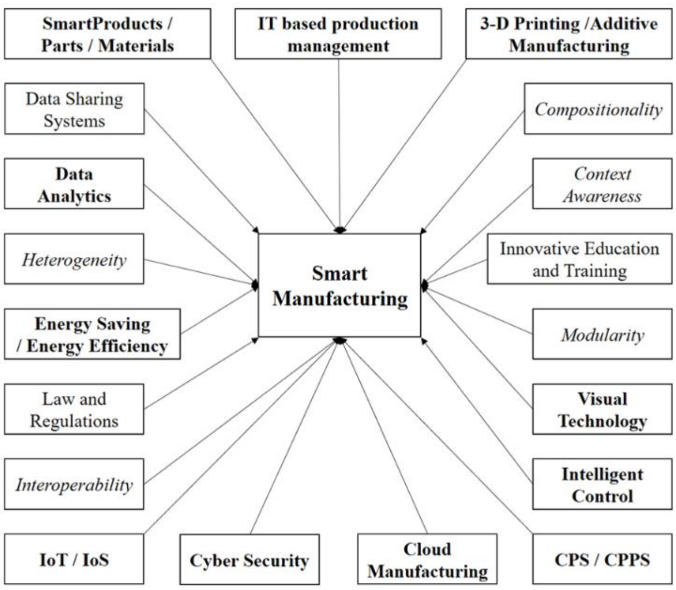

Figure 2. Smart manufacturing and related to it areas (Mittel et al., 2017, pp. 1352-1353)

Therefore, smart manufacturing can be considered as a transformation of factories' functioning and its shift to a new advanced level. This transformation might bring new opportunities and advantages to factories. However, its implementation is still in progress and faces various difficulties. A considerable number of technology-related processes namely digitalization, automation, and virtualization should take place to enable it (Kusiak, 2017, pp. 514-516).

2.2 Development path of AR

This section provides a brief description of AR history. A visual step-by-step progress of AR development, emphasizing its most important events, is presented below (see Figure 3).

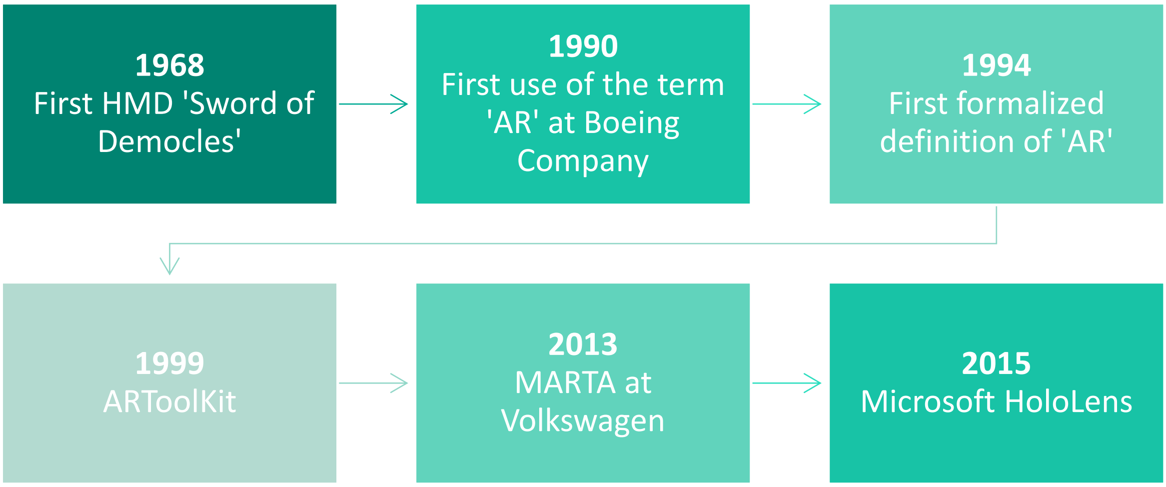

Figure 3. History of AR development

The history of AR started in the 1960s (De Pace et al., 2018, p. 1). As can be seen in the figure above, a professor at Harvard University Ivan Sutherland created the first head-mounted display (HMD) in 1968. This event is considered as the first appearance of AR. Its core technological developments are still used in the current AR and VR devices. Afterward, in 1990 Caudell and David Mizell developed the first HMD for cable assembly purposes at Boeing. The technology was able to demonstrate its benefits by saving the company's resources considerably (Sünger et al., 2019, p. 121). As noted by De Pace (2018), the concept of AR was officially formalized by Milgram and

Kishino in 1994 and was defined as ‘the relationship among real space, virtual space and all the intermediate forms of mixed space’ (p. 1). Moreover, the author stresses that in 1999 ARToolKit was launched by Hirokazu Katu, which was the first case when AR was released as an open-source software library. Sünger et al. (2019) describes one of the next important contributions of AR to the manufacturing industry which occurred in 2013 when Volkswagen presented its Mobile Augmented Reality Technical Assistance aka MARTA. The system helped workers with soft- and hardware components during the production process of automobiles. Besides, the author states the most recent step in AR history that pushed the development of this technology. It was the launch of Microsoft HoloLens in 2015. They could be regarded as MR smart glasses which were fully supported by Windows 10. They were even used by NASA for interactive tours (pp. 121-122).

Since then, enhancement and application of AR among all spheres have taken place significantly. Yet, this thesis focuses predominantly on the application of industrial AR, which development path is reviewed in the next subchapter.

2.3 Development path of IAR

Fite-Georgel (2011) affirms a simple and broad definition of Industrial Augmented Reality (IAR). It states that IAR means ‘applying Augmented Reality to support an industrial process’ (p. 2). As has been already mentioned in the last subchapter, the concept of AR application in the industry appeared when Caudell and Mizell integrated it into Boeing manufacturing processes. Although some common grounds can be found in the history of AR and IAR development since the existence of the latter one would not be possible without the invention of the former one, it is still crucial to mention some milestones of IAR development.

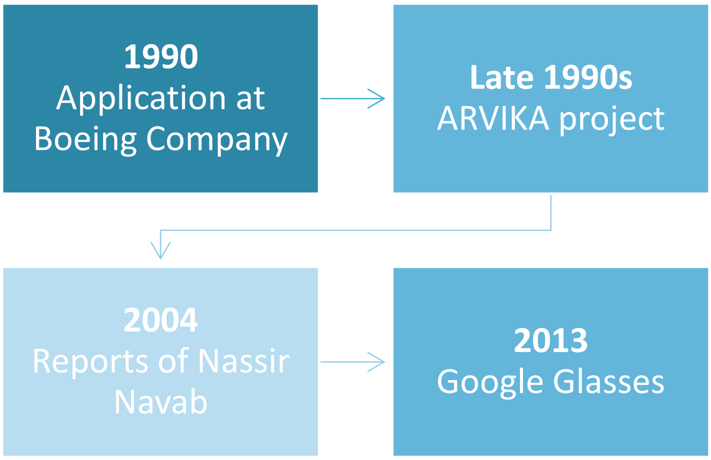

Figure 4. History of IAR development

Fite-Georgel (2011) places emphasis on the valuable initial project which contributed to the IAR progress called ARVIKA. It was founded and funded by BMBF (German Federal Ministry of Education and Research) and aimed at exploring opportunities for AR in an industrial environment (p. 2). Even though the results of the project appeared to be not as promising as had been expected, it pushed the development of IAR by demonstrating its fields of application, future possibilities, and areas for improvement. In addition, it initiated a few other European research projects such as ARTESAS (Advanced Augmented Reality Technologies for Industrial Service Applications), focused mainly on AR employment in aerospace and automotive industries (Fraga-Lamas et al., 2018, p. 2), and START (Service and Training through Augmented Reality), aimed at triggering R&D in IAR sphere (Navab, 2004, p.16).

Fite-Georgel et al. (2011) assures that Nassir Navab made a crucial contribution to IAR history by providing reports and analyses on IAR work at Siemens and advice on its future integration into the industry (p. 2). For instance, in his work ‘Developing Killer Apps for Industrial Augmented Reality’, Navab (2004) described the application of AR in some industrial procedures and emphasized the importance of technology’s reliability, user-friendliness, and scalability beyond simple prototypes (pp. 16-20).

Overall, in all of the cases reviewed in this section, the IAR systems were mostly created for experimental purposes, and only in the last decade, there was a move to scalable meaningful commercial offers such as Google Glasses in 2013 that drew people's attention significantly and introduced IAR to a broader public from the beneficial side (Fraga-Lamas et al., 2018, p. 2).

2.4 Definitions and concepts of AR

Before providing an overview of the main AR components, it is firstly important to clarify what Augmented Reality means. It can be stated that with time people have started to understand AR technology more profoundly and were able to define it more precisely.

One of the first researchers in this field was Ronald T. Azuma. In his paper 'A Survey of Augmented Reality' (1997) the author identified the concept of AR and attempted to describe its distinctive characteristics and the fields of its possible application. According to Azuma (1997), AR is a technology that 'allows the user to see the real world, with virtual objects superimposed upon or composited with the real world' (p. 356). He also determined three main features that all AR systems should have:

- Combination of real and virtual
- Interaction in real time
- Registration in 3D.

One of the modern definitions of AR claims that it is 'a hardware-software system able to overlay virtual images or objects on the real world visual, to give to the observer information that he could not obtain by using only the interaction of his/her physical senses with the workplace' (Dalle Mura, 2021, p. 4). It can be seen that the main idea of the definition remained the same, but it became wider and more exact in terms of providing specifications and explanations of what AR is and what its purpose is.

Another important thing to be mentioned is the 'Reality-Virtuality continuum' (RV continuum) and AR location in it. The concept was formed by Milgram P. and Kishino F. in their work 'A taxonomy of mixed reality visual displays' in 1994.

In terms of RV continuum, there are two extremes: a fully real environment (on the left) and a fully virtual environment (on the right). Everything that is situated between these two environments combines elements of both realities. As long as the real environment prevails and virtual objects are added to it, it is augmented reality. On the contrary, when it is mostly virtuality with some objects brought there from a real world, it becomes augmented virtuality. Although there are examples of both these realities nowadays, it is still complicated to define a distinct difference between these two definitions (Egger et al., 2019, p. 5).

Therefore, considering different definitions and concepts, it can be generally claimed that with time the concept of AR has changed, and its explanation also has not stayed the same. Nevertheless, in view of everything that has been mentioned so far, one may suppose that AR has been always connected with the augmentation of the real environment that a person interacts with and the support and guidance of one's actions in it.

2.5 Key AR components

The last thing to be mentioned before going deeper into the essence of the paper is AR components. There is a simplified scheme and explanation of the process of how AR devices work and with the help of which components (see Figure 5). This paper does not analyze thoroughly the technical side of the technology work since it is mainly focused on the implementation and integration of AR into the industry. However, some key concepts should be mentioned and explained in order to provide a better understanding of the further review.

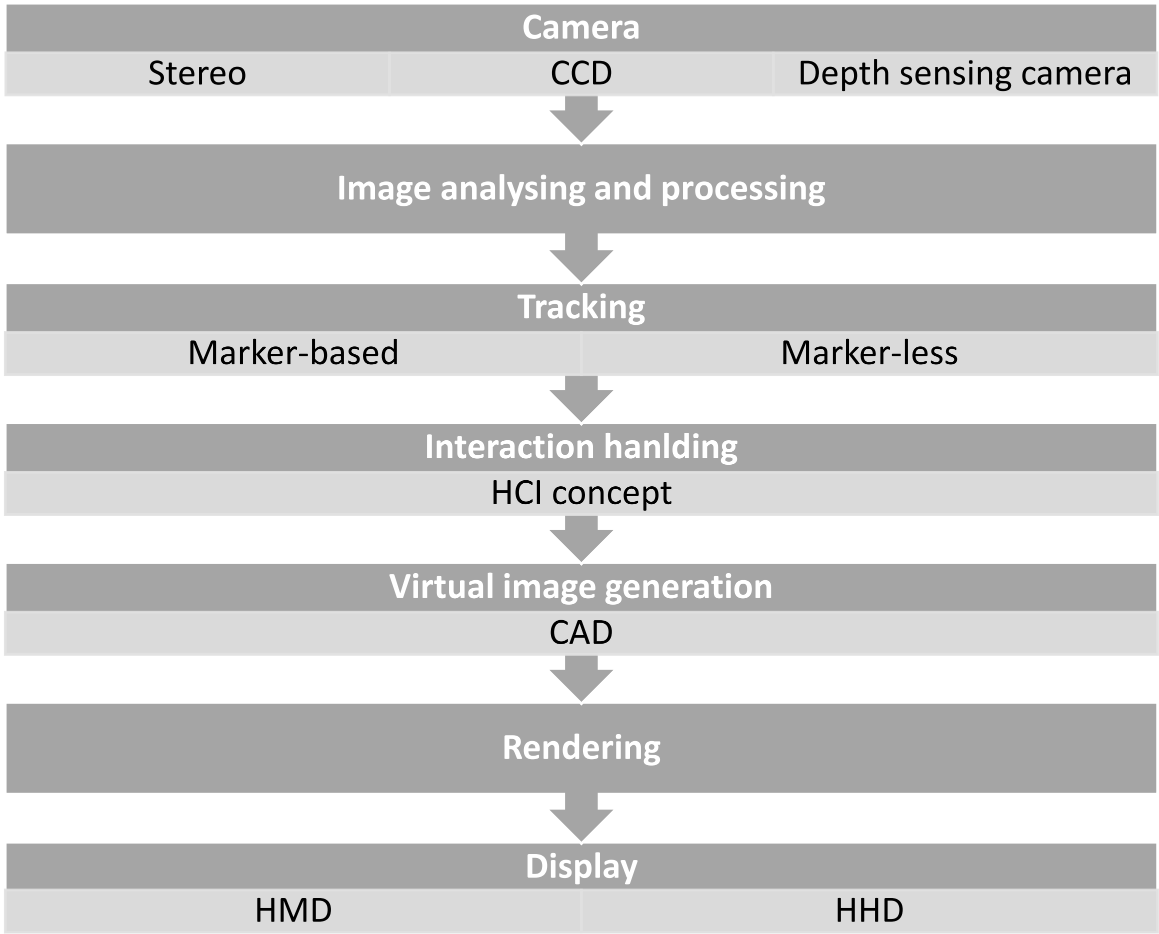

Figure 5. Simplified representation of AR work

Qui et al. (2019) brings attention to the first device that AR uses: a camera to see and capture things that are happening around. The most well-known types of cameras are charge-coupled devices (CCD), providing live video stream; stereo, including two or more lenses and capturing three-dimensional images; and depth sensors, enabling to see depth of the objects.

The next step is to analyze an acquired image and process data from the camera with the help of AR software and internal sensors. This stage is needed for the technology to understand the general placement of the camera in a real world related to both a worker and objects.

Afterward, there is a necessity for the tracking process to come into action. It enables the detection of the position of a future AR object with the help of real-time sensors. There are different types of tracking, however, in this work only two of them are mentioned since they comprise the basics of AR functioning. Firstly, it can be marker-based tracking, which allows to position an object in the right place with the help of markers put in the working environment. The second option is marker-less tracking which does not require any markers for work. It scans the surrounding environment and, based on certain features, helps to place the object correctly (p. 600).

The stage of interaction handling covers a very important for the current theme aspect which is called HCI or human-computer interface. It enables interaction between a human-being and a computer with the help of, for example, voice recognition, gesture recognition or biometric sensing and is normally integrated into different physical input and output devices such as, for instance, microphones, gloves, or glasses. With its help, one can avoid occlusion and combine objects from the virtual and real world (Tao et al., 2019, pp. 109-112).

The next process is the generation of the virtual image which will be later laid over the reality. It is implemented with the help of CAD (computer-aided design) which allows to create 3D models (Dalle Mura et al., 2021, p. 4).

After the virtual image is created, it should be overlaid over the real environment. However, before being sent to the display, it overcomes the process of rendering. As defined by Qui et al. (2019), rendering 'is a process used to add parameters to the assembly model in the AR environment and output them in the form of video…' (p. 601). Simply saying, the produced image has to be changed to an appropriate perspective so that the user gets a good picture of the AR object.

Last but not least, the image is demonstrated in the display. In this paper, only two basic types of displays are mentioned. HMD (head-mounted display) allows a user to have free hands because it is worn on the head, and it provides an immersive visualization. One of the most well-known HMDs are Google Glasses and Microsoft HoloLens. As for HHD (handheld device), they limit the freedom of workers' actions since they should be held with hands. Moreover, they cannot give the same feeling of immersion as the previously mentioned display (Dalle Mura et al., 2021, p. 6).

Therefore, in this section, we considered and described the most relevant components and stages of AR functioning. Although in reality the whole process includes more nuances and complications, the current level of knowledge and explanations is sufficient for further understanding of the paper.

2.6 Key state-of-the-art AR applications in manufacturing

This chapter can be considered the central part of the literature review since real-life usage of AR technologies in the last few years and at present will be discussed here. Current work does not cover all possible AR applications in smart manufacturing, it mentions the most outstanding and highlighted ones.

De Souza Cardoso et al. did a comprehensive summary of IAR applications in different industrial segments with the help of a diagram provided below.

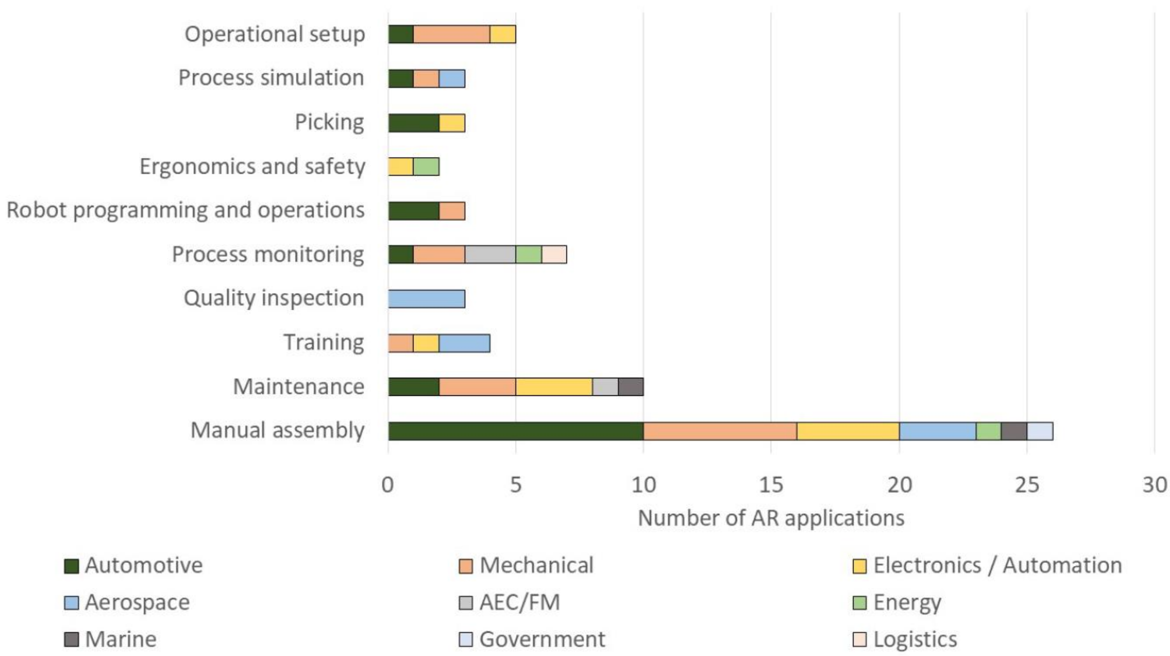

Figure 6. IAR application in different industrial segments (De Souza Cardoso et al., 2020, p. 8)

This graph allows us to conclude that, firstly, AR is already used or at least has started to adapt in some industrial processes, and secondly, it is not utilized equally in different tasks and industrial segments. For example, it can be seen that manual assembly in automotive or mechanical industries comprises the most considerable part of IAR utilization, whereas it is not so common that picking tasks are supported by this technology and it mostly occurs in automotive and electronics spheres. Despite these differences, it can be said that in general nowadays the level of AR usage in industries is higher than one could have assumed.

Further subsections will scrutinize and provide examples of IAR application in some of the above-mentioned processes of manufacturing. The order of application areas is not based on their importance, but on their logical sequence during the manufacturing process.

2.6.1 Training of inexperienced workers

The first thing to be settled when a new worker comes to any industrial enterprise is to teach this worker how to implement one's job. A conventional way of training is a transfer of knowledge from the expert to the novice. However, it is very time- and cost-consuming. That is why some companies started to apply integrated AR assistance for training new inexperienced workers.

Dalle Mura et al. (2021) explains that the usage of AR in workers' training is distinguished by the content of the instructions. It is implied that new workers should learn everything from scratch, therefore, they are provided with an explanation of each object (instrument, detail, etc.), action, and safety rules of its implementation. These instructions are shown in glasses and overlaid in a real working environment (pp. 14-15).

One of the global companies that use AR in its training processes is BMW. HoloLens is employed in their AR training. The novice can complete training with real-life and augmented objects, get detailed text, video, and image instructions, be guided throughout the whole process by the device, and see the results and feedback at the end. It saves time for other expert workers since they do not have to teach new ones. Moreover, it led to cost savings due to eliminating the need of using trainers' time (Capgemini, 2019, 0:08-4:13).

Another example highlighting the usefulness of AR in training in terms of security reasons is presented by Fite-Georgel (2011). The author reveals how AR simulator helps to train new welders. He mentions its advantages such as safety (which is crucial since the job of welder is very dangerous and training in a real-working environment can be hazardous), the effectiveness of teaching, its availability, and constant presence of instructions and feedback (p. 5).

2.6.2 Logistics and order picking

Before starting assembly there is a need to put logistics into action to find needed details in the warehouse. Traditionally, it is required from logistics workers to resort to paper-based picking lists or information about the parts on the PC/tablet. AR technology allows workers to get access to all necessary information on the display of glasses, for instance, they can see the location of the detail, its number, and the shortest route to it. Moreover, AR glasses are able to work as barcode reader that lights up green when the right product is found. Augmented Reality application in order-picking enables reducing picking up time and errors connected with it which are often a cause for the delays on the production line (Dalle Mura et al., 2021, p. 12; Fite-Georgel, 2011, p. 4).

One of the companies that integrated UbiMax smart glasses into picking up operations is Volkswagen (VW) at its headquarters in Wolfsburg, Germany. The method and technology described in the previous abstract are applied in their in-plant logistics tasks. In 2015 VW carried out 3 months pilot project to test the efficiency of AR glasses. It turned out to be a success, and this technology started to be gradually integrated into the factory logistics on a voluntary basis. Mario Kuznack Bodner, a member of Works Council emphasized the importance of this project since the real value of the device could have been estimated only in practice. Moreover, he stressed that by introducing AR early enough the company was able to gain the benefit from receiving feedback from workers and hence improving glasses for further use in terms of HSE (health, safety, and environment) (Williams, 2015).

2.6.3 Guidance for expertise workers in assembly, maintenance and repair

In this work guidance for assembly tasks, maintenance and repair are gathered and described in one section because the core concept and the way of AR functioning in terms of providing support to experienced workers in these three areas remain approximately the same. The main purpose of AR in these tasks is to reduce time and consequently costs spent on the above-mentioned operations by delivering virtual instructions and distant assistance to the user.

Moreover, one of the key issues that AR addresses in assembly, maintenance, and repair is reducing the mental load and attention wandering of workers by allowing them to reject manual instructions and giving access to all needed information 'live'. AR application in the above-mentioned procedures is expected to reduce the costs by around 25% and enhance the performance by 30% (De Pace, 2018, p. 2).

Assembly

Considering assembly and AR usage cases in it, it can be mentioned that the assembly process varies considerably for different products, therefore, it is complicated to adjust the whole system of AR to a new set of instructions. However, there are a lot of examples of companies that either started to integrate AR in their assembly or have already gained benefits from its usage.

For instance, AIRBUS held a project named MOON (assembly-oriented authoring augmented reality) focused on the creation and provision of instructions for assembly in the aerospace industry with the help of AR (De Pace, 2018, p. 3). As Serván et al. (2012) explains that the process chosen for the current case included the task of routing electrical harnesses in the military aircraft A400M. By analyzing inputs from virtual and real worlds and processing them, Augmented Reality provided the output in the form of visual instructions for workers. The results of this project were positive since the MOON method allowed us to achieve significant time savings (pp. 636-638). It can be observed in Table 1 below.

Table 1. MOON method time savings (Serván et al., 2012, p. 639)

MOON USE CASE	**WI Creation Time (h)**	**WI Consulting Time (h)**	**WI Maintenance Time (h)**
Conventional Method	30	2	10
MOON Method	3	1	1

As can be concluded from the table above, even in a project with limited executed tests, the outcomes were already promising. Firstly, the time of model creation was diminished by 90% because thanks to the MOON methodology the time spent on the generation of the model and human intervention are minimized. Secondly, consulting time for the assembly became two times less than with the conventional method. Such a win on time was achieved since the system used natural markers and enabled an easier 3D drawings interpretation which in its turn reduced error occurrence. Finally, it reduced the time spent on maintenance by 90% because it reused information from PDM (Product Data Management) which was already generated before to produce a new solution (Serván et al., 2012, pp. 639-640).

Another successful example of AR integration into the assembly process can be NASA with its Orion capsule assembly and the usage of HoloLens AR HMD (Dalle Murra, 2011. p. 11). Assembly of the aerospace capsule is a complex task and asks a lot of knowledge and studying of massive paper instructions. Usage of AR headset provides all needed instructions with the help of visual overlaid elements. The worker sees which actions s/he has to do and what a final product should look like. Although ergonomics still needs to be enhanced, and it is hard to work with the headset for more than 3 hours, it is proven that workers understand all processes much faster and are able to perform them in a shorter period (Winick, 2018).

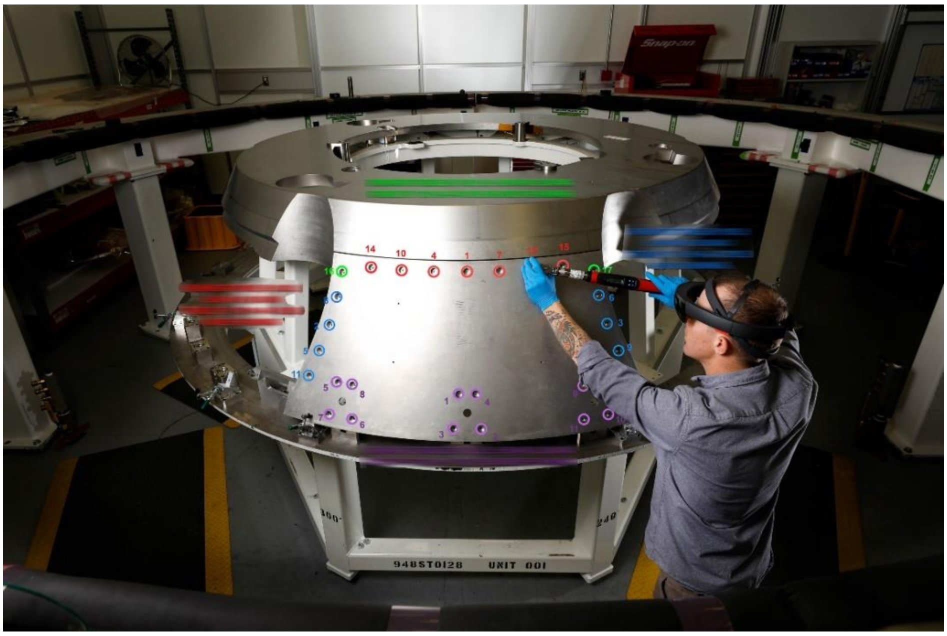

Figure 7. Augmented reality view of technician working on machinery (Winick, 2018)

Maintenance and Repair

Another important field of application is maintenance and repair. A substantial amount of time and resources are spent on it by companies. As for workers themselves, it requires deep knowledge, constant reference to guidelines or the help of some other experts. Moreover, taking the current pace of technological progress and changes brought therewith into consideration, there is a need for continuous learning of new processes.

Augmented Reality devices can provide workers with assistance, and as Sünger et al. (2019) states, it saves time, and money and makes it possible to avoid human errors during these processes (p. 128).

Let us refer to NASA AR projects again to provide an example of repair and maintenance tasks with this technology. Since the further an astronaut from the Earth is, the longer the delay in communication with Mission Control Center is. Thus, AR glasses which will be able to provide instructions and assistance removing the need to connect with the Earth are of crucial importance. Moreover, it will allow an astronaut to avoid reading paper instructions, have free hands (since there is no need to hold any devices), and solve a problem faster on one's own. Several projects were held to test HoloLens glasses in use in spaceship repairs and maintenance including T2AR project in orbit implemented by Japanese astronaut Soichi Noguchi, Sidekick experiment carried out by former NASA astronaut Scott Kelly, and tests executed by ESA astronaut Thomas Pesquet and NASA's one Megan McArthur. All the above-mentioned projects have shown that although there is a need for improvements, AR can be successfully used for astronauts' assistance for repair and maintenance tasks in spaceships and that it can bring enormous benefits to this field not only by increasing efficiency and accuracy of tasks execution but also by boosting space exploration since astronauts will be able to fly further from the Earth (Guzman, 2021).

One of the techniques that are also worth to be paid attention is tele-communication. It is widely mentioned in academic papers and applied in real-life cases to refer to AR application in maintenance and repair. Tele-maintenance implies 'remote maintenance provided by means of a telecommunication system' (WordSense Online Dictionary, 2022, tele-maintenance). It means that a remote technician can connect via the software to AR glasses and help the worker with maintenance or repair tasks, which leads consequently to the conclusion that the problem can be solved faster and with fewer costs.

To clarify a way of AR functioning in this task, an example of TAE Aerospace company with its FountX AsR (Assisted Reality) technology will be taken. This device consists of AR glasses, a camera, a microphone, and a speaker. It allows a technician who is located on-site, where repair or maintenance for an aircraft engine is needed, to connect online with an engineer that can be in any other spot worldwide. The latter one can see a video on his/her PC or tablet from the working place and can provide live feedback to the former one. Therefore, there is a live connection between two people, which helps to eradicate a problem faster and cheaper since there is no need for an engineer to come to the work site (Safi et al., 2019, p. 1189; TAE Aerospace, 2017, 0:17-1:30).

2.6.4 Quality Control and Inspection

Quality control has been gaining more and more popularity during the last century. There is an inclination to comply with a standard of perfection as much as it is possible to produce and bring to the market flawless products. Consequently, the objective of finding a more effective, accurate, and faster way of product inspection is of considerable importance for manufacturing companies. AR technologies are one of the ways how to achieve this aim. With AR devices it is possible to directly compare a virtual expected perfect model with the produced one by superimposing the former virtual version on the latter real one and immediately identifying defects or discrepancies. It leads to execution time minimization, elimination of possible mistakes caused by human factors and hence cost reduction (De pace et al., 2018, p. 3).

One of the prominent cases of AR application in quality control is Renault Trucks. In 2017 they started to test HoloLens glasses for inspections of the product quality in a factory in Lyon by examining a ready engine. With HoloLens and software developed by Immersion, employees are able to see a sample model, instruction, and each part separately to assess its compliance with the initial prototype (Palladino, 2017; Renault Trucks Official, 2017, 0:00-1:25).

Porsche also integrated Augmented Reality into their quality control processes in Leipzig in 2018 by means of the tablet app. The main process of its functioning is still the same: CAD-image is imposed over the real part of the car, compared with it, and if any discrepancy is found, it lets the worker know where, what, and how it should be changed. Porsche management claims this technology to be a worthwhile innovation that will help to increase the quality of their cars considerably (Porsche, 2018).

2.7 Challenges of IAR deployment in smart manufacturing

After examining academic papers on IAR and cases of its real-life application, the main challenges that prevent this technology to integrate smoothly and fast into manufacturing industries were identified. Although the number of all existing issues is genuinely wider, it is considered that for this work it is sufficient to reveal only the biggest challenges since some profound technical concepts are not the essence of this paper.

The main directions of the AR challenges in terms of its integration into industrial processes of manufacturing are demonstrated in Figure 8. A broader explanation and disclosure of each point are provided after the scheme.

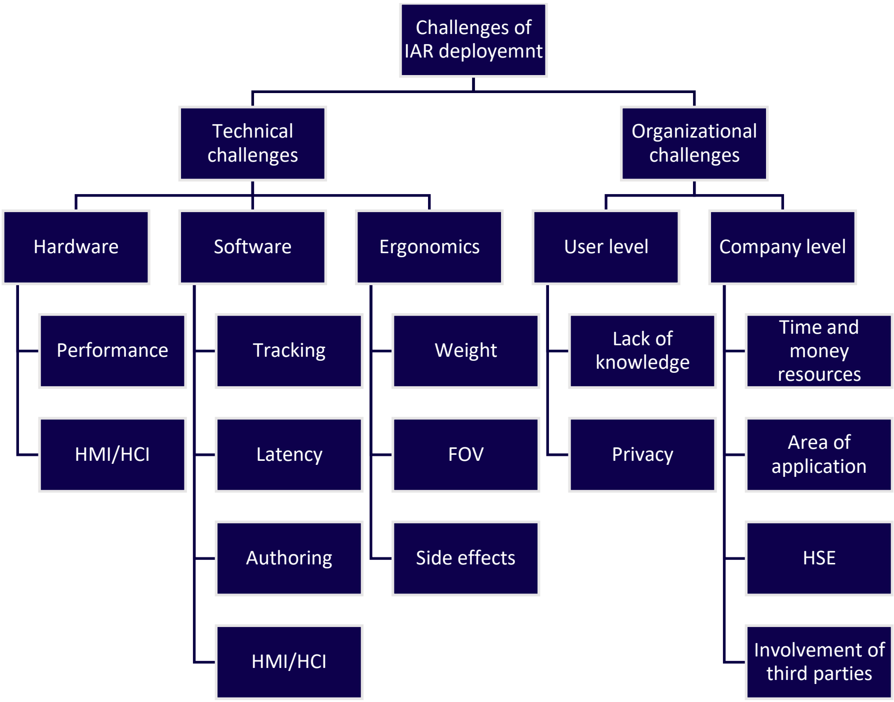

Figure 8. Challenges of IAR deployment in smart manufacturing

2.7.1 Technical challenges

The first challenge to be referred to is technical difficulties that companies developing and implementing AR face. They relate to hardware and software performance of Augmented Reality devices, as well as ergonomic problems that are aroused from the usage of technology by employees.

Hardware

As Egger et al. (2019) claims, although the processing speed of the hardware has been enhancing considerably over years, it still remains a problem for AR technology, especially for the marker-less HMDs (p. 19).

Software

Since the main performance part depends on the software development and its improvement, there are more issues in this field. Although AR is already used in some areas of manufacturing tasks, its software still needs to be optimized in certain aspects.

Tracking

Tracking methods are often regarded as a feature that requires improvements. Such specifics as 'accuracy, flexibility, robustness, computation efficiency, [and] ease of use' are the crucial for tracking systems in AR. However, issues like the occlusion of markers that allow AR system to orient in space and the impossibility to utilize markers on some details because of their small size or, for example, because of the shadows from other assembly objects, remain unsolved. Since marker-less tracking is more advanced than marker-based one, it faces even more problems. This tracking method requires development to achieve its maturity, especially in terms of better localization and mapping (Dalle Mura et al., 2021, pp. 18-19; De Souza Cardoso et al., 2020, p.12; Egger et al., 2019, pp. 20-21).

Latency

The problem of latency is added to it. Time is needed for the software to process the environment around, which changes depending on the actions of a worker, and understand which image to demonstrate (Dalle Mura et al., 2021, p. 19; Egger et al., 2019, p. 21; Masood et al., 2020, p. 25).

Authoring

Another point mentioned in academic papers is authoring. Based on the definition in the Cambridge Dictionary, authoring is 'the design and production of computer programs and websites, using special software' (2022, authoring definition). Connecting it with the theme of AR systems, there is a necessity to create a working program for AR that will function for the good of the factory and its needs in different manufacturing processes. Yet it is a complicated task since there are no standardized guidelines for AR authoring, which makes the process of creating software and program for AR devices very time-consuming and expensive. Apart from it, AR authoring requires access to a vast amount of data related to the assembly procedures which can be considered private information of the company (Dalle Mura et al., 2021, p. 19; Egger et al., 2019, p. 21; Masood et al., 2020, p. 25).

Hardware and Software: HMI/HCI

One of the central concepts for all technologies of Industry 4.0 including AR is Human-Machine Interface (HMI) or Human-Computer Interface (HCI). HCIs 'provide the user with different visual, haptic and auditory sensations, which play a vital role in a virtual assembly system for increasing the degree of immersion in the VR/AR environment' (Tao et al., 2019, p. 11). Therefore, the appropriate hardware choice and constant software enhancement in terms of HCI, especially through NLP (Natural Language Processing) and gesture recognition, can lead to a closer and more efficient Human-Robot Collaboration (HRC) and consequently more effective utilization of AR technology (Della Mura et al., 2021, p. 18; Egger et al., 2019, p.21; Tao et al., 2019, p.12-14).

Ergonomics

In current work ergonomics is referred to as the technical challenge because technologies are aimed at addressing or at least improving the physical and mental well-being of workers and comfortability of working processes, however, as specified by Reiman et al. (2021) 'technological development has not handled and solved all existing challenges related to human health, safety, and productivity in industrial manufacturing processes. Humans will continue to play active roles in manufacturing processes' (p. 1). That is why it is necessary to take the opinion of employees into consideration. As for the ergonomics side of AR devices, workers are still rather dissatisfied with it. The first complaint of users is about the weight of hardware devices. It concerns preliminary HMDs since they are heavy, and it is difficult physically to wear them for the whole working day. Secondly, the field of view (FOV) of AR glasses is less than human's one which in a long-term can cause headaches, dizziness, and nausea. Finally, after the continuous period of AR HMDs usage, various side effects were reported: visual fatigue, decrease in performance concentration because of the 'noises' created by the displayed information (Egger et al., 2019, p. 19; De Souza Cardoso et al., 2020, pp. 11-12).

2.7.2 Organizational challenges

Challenges referred to organizational level concern both sides of potential users of AR devices: management or board of the company and workers themselves. It is important to consider challenges for everyone because, firstly, without the agreement of one side the usage of the technology is impossible, secondly, the reasons for unacceptance are completely different.

User level

Users are workers themselves who apply AR devices in manufacturing processes. Their main reason for not accepting AR can be solely a lack of knowledge about it, which can make users suspicious and even scared of the change (Masood et al., 2020, p. 25). Moreover, since AR system can perform and improve only if it can access task or error tracking, workers express concerns about their privacy because of the additional surveillance the system adds up (Egger et al., 2019, p. 21).

Company level

Concerns of the management of the company refer to other subjects and comprise more doubts since the decision of implementing new technology into manufacturing processes often comes from them.

First of all, it is important to understand that a company primarily assesses how beneficial innovation is in terms of money and time. Thus, a comparison of investment into technology and its potential advantages brought to the company in the future is to be estimated. The time needed to integrate the technology and receive a maximum out of it is considered by the company as well. For example, Masood et al. (2020) stresses that the cost of hardware was not found as a problem by companies that took part in his experiment. However, it was regarded problematic to scale up the software application since its incorporation and authoring of content is a complicated task (p. 22). Consequently, it asks for both financial and time resources, and these possible complications make companies doubt the investment.

Apart from it, Egger et al. (2019) emphasizes that to profit from the utilization of AR technology, a company should understand that this technology is not suitable for all the tasks in manufacturing. Some of the processes are mature or efficient enough and the usage of AR will just disrupt them. Hence, the right choice of usage areas of Augmented Reality devices is another challenge that the top level of the company must face.

Another issue for the management of the company that the authors assert is connected with HSE (Health, Safety and Environment) concept. The challenges concerning health were already mentioned before while describing technological and ergonomic problems. We also have briefly mentioned safety issues in regard to data sharing, supervision, and authoring system. As for the last part of this concept, a company will have to overcome a lot of environmental changes since the integration of new technology brings alterations at all levels and include not only modifications in organizational structure, manufacturing, and training processes, but it concerns the culture and working environment of the whole firm itself. For instance, the integration of AR can highly likely bring the necessity of external support. It can cause anxiety as some companies are unwilling to involve third parties and give access to their private information (pp. 21-22).

2.8 Future perspectives of IAR in manufacturing

As was reviewed in the previous sections, although the integration of IAR into manufacturing has already started and there are prominent examples of its usage and efficiency, there are still issues to be addressed and faults to be fixed. However, the presence of problems should be not only considered a negative fact, it also brings its positive side since it allows actors of IAR sphere to understand ways of improvement of the technology, i.e., what problems should be resolved, what features should be refined, what possibilities for the further enhancement there are.

In this subchapter, we will cover the main areas of AR improvement for its better utilization in the manufacturing field and provide an example of a potential combination of AR and other technologies that already start to grow in popularity.

2.8.1 Future directions of improvement

Figure 8 already gave a general understanding of the directions, in which AR technology should be improved to become more efficient and integrate into manufacturing faster. To give a better understanding of why these problems matter and should be eliminated, comments in the existing issues will be provided.

Hardware and software

Solution of hardware and software problems lie at the core of the AR enhancement since the performance and applicability of the technology depends on them.

Egger et al. (2019) describes and explains in detail what and why should be changed in the future for a better execution of IAR. The first crucial improvement to be made is to increase processing speed of AR devices since the working environment and processes become more complicated and require technology to work faster. For example, marker-less technology starts to be used more widely nowadays, meaning that AR will need a better processing speed to orient quickly in the working environment without any markers.

Moreover, the system should be more adaptable to real-life applications in terms of adjusting to the users and their experiences. It implies that depending on the experience of an individual, a system will show a specific content corresponding with a person’s knowledge and needs. Without this enhancement, AR will not accelerate manufacturing, but rather hinder it.

Besides, common, and standardized guidelines and data should be used for AR systems so that they can be easily integrated into the IT infrastructure of a company and adapted for various purposes. The need for this unity is also caused by an authoring problem that was already mentioned in the previous subchapter. Such authoring systems should be created and used so that the content can be added and edited from both ends of the system. This will lead to the decrease in time required for content creation (pp. 22-23).

Ergonomics

Even if technical issues are addressed, without the device being appropriate and comfortable for the workers' usage, it will not be able to integrate into the industry widely. That is why problems concerning ergonomics should be defined and solved as well.

The two concerns to be changed in the future that are mentioned often in academic papers and experiments: the weight of the devices and content visibility including FOV. Both factors prevent devices to be employed for a long period. It leads to physical and mental discomforts (Egger et al., 2019, p. 22; De Souza Cardoso et al., 2020, p. 12).

Organization

As was already defined, at the organizational level there are issues connected to two main parties: users or workers and management of the company. There is a brief review below of how the level of their concerns can be reduced.

User level

The difficulty to integrate AR into the working processes that one can face from the side of the employers is their lack of acceptance of a new technology. To increase their openness to AR, they need to be introduced to and get familiar with it profoundly beforehand. To accept something, one needs to see its advantages and drawbacks. Therefore, as Egger. et al. (2019) and De Souza Cardoso et al. (2020) suggest an appropriate way to achieve this goal is needed which implies implementation of experimental tests in the working environment of manufacturing companies to explain and show workers how AR functions and what benefits it can bring to them. In fact, it can be valuable for the company as well since the system can be adapted and enhanced during its testing (p. 23; p. 12).

Company level

There are a lot of matters that should be taken into consideration by manufacturing companies themselves before and while implementing AR. However, Egger et al. (2019) summarizes it very precisely that since the implementation of AR results in a great number of changes in the company, starting from the company culture to its ways of managing data, management should assess risks and choose the right area of technology application beforehand. Only being prepared for a change and understanding where and how to apply technology, AR can bring success to a company (p. 24).

2.8.2 Development trend: a combination of AR and DT

Nowadays another promising technology such as Digital Twin (DT) also develops and gains popularity. The combination of AR and DT is considered to be a very auspicious combination of technologies since DT can increase the effectiveness of AR in terms of safety, productivity, accuracy, and economy. However, this combination is supposed to be applied and bring benefits only to assembly processes of manufacturing.

Digital Twin was defined by professor Grieves at Michigan University in 2003 as ‘a digital system including physical and virtual products, and the connection between them…’ (Qiu et al., 2019, pp. 598-599). In other words, as the authors of this paper explain, by having access to all data of a certain object, DT can analyze and improve it in a digital world so that when the item is produced it does not have any drawbacks, hence, it reduces or eliminates manufacturing defects. Moreover, DT can provide hints for the improvement of physical entities by creating new ideas and problem solutions. The benefit that DT can bring to AR is that in comparison to the latter one alone, which bases analyses and navigation on static models and data applied to an ideal situation, the former one is able to make immediate adjustments to assembly processes and their optimizations with the help of assembly models obtained from the real data and the real-time analysis of the assembly state of the physical model. These technologies applied together can raise the accuracy of assembly and enhance control of the assembly behavior in general (Qui et al., 2019, pp. 598-599, 605).

2.9 Synthesis of the theoretical framework

Taking everything into account, it can be concluded that manufacturing industry is currently focused on the integration and utilization of advanced technologies of Industry 4.0 which combine real and virtual worlds, and Augmented Reality is an integral part of this smart manufacturing and consequently smart factories. It had a long development history dated back from the 1960s and is still developing nowadays. There are already examples of AR applications and its effectiveness in several manufacturing processes such as:

1. Training
2. Logistics
3. Assembly
4. Maintenance and repair
5. Quality control and inspection

However, AR systems and devices still require enhancements. Their drawbacks prevent them from being integrated into manufacturing widely. Disadvantages and areas of improvement are mainly connected with

1. Technical challenges
2. Organizational challenges

The elimination of these issues can considerably boost AR deployment, but this process will take time because it depends not only on the desire of the AR creators but on technological evolution in general, a better understanding of the technology by all actors and what is more important - its acceptance by them.

The work on AR improvement already takes place at present, and new ways and combinations of technologies, from which AR systems and hence companies can benefit, are being found. For instance, joint usage of AR and DT can bring a more efficient, economic, and safer working experience, which is advantageous for companies.

Therefore, Augmented Reality has already started its integration into manufacturing, and if requirements for its future successful development are met and treated with particular care, and AR systems are applied in areas to which it can bring true value and which it can improve, the technology can be considered as promising for the manufacturing industry.

3 Methodology and Implementation

In this chapter, the chosen research methodology and the way of its implementation are explained. They are selected and executed in accordance with the Saunders' research onion (see Figure 9).

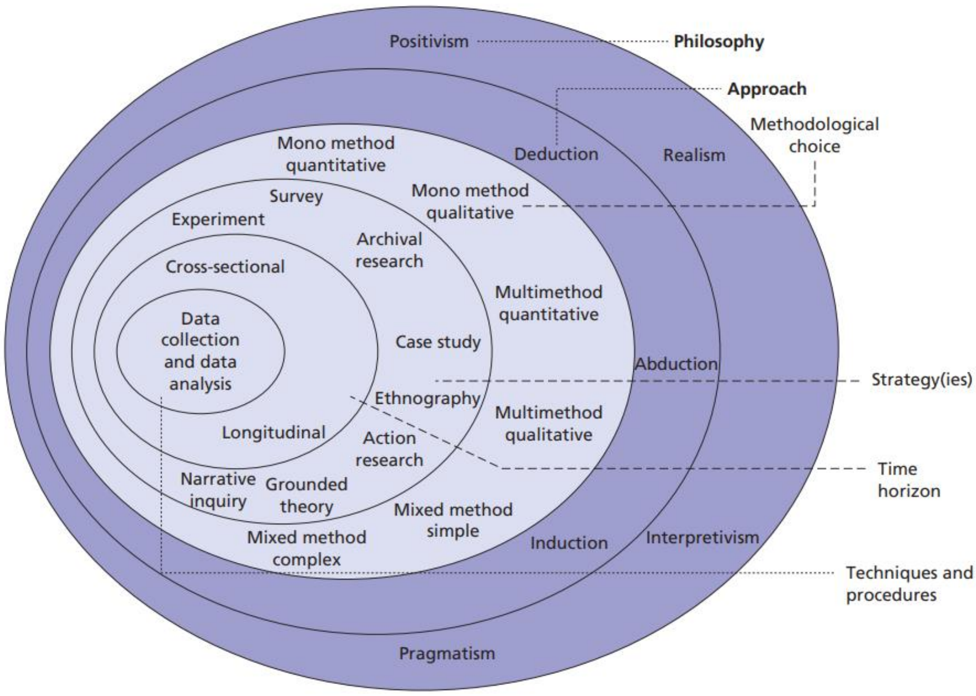

Figure 9. Research onion (Saunders et al., 2012)

3.1 Research design

Research design is a coherent and consequent way that helps an author of the work to answer research questions thanks to different methods and techniques that correspond to the needs of the research (Saunders et al., 2012). Hence, it is crucial to create a suitable research design since the success of the whole research depends on it.

Approach

Saunders et al. (2012) reveals the essence of the inductive approach, which is thought to be the most suitable one for most social science studies. It implies that firstly the data is collected and then based on it, conclusions are made. Such an approach is very useful when one tries to understand the core of a problem or a specific theme. Moreover, induction allows more freedom in terms of finding alternative solutions to a chosen problem. Instead of proving something, one simply analyses data and tries to understand the connections. Therefore, the purpose of this approach is perfectly corresponding to the needs of the presented work. In terms of this research inductive approach was applied to create a perspective model of IAR development paths in smart manufacturing that can be followed and verified later.

Nature of studies

For the further explanations of methods, it is also important to know that the nature of this study is exploratory. It brings insights into the chosen topic to lead to a better understanding of the current situation and define potential futures of the issue area. This method is very flexible and adaptable meaning that it allows deviations and changes in the direction when one obtains new data (Saunders et al., 2012).

Methodological choice

In this research both quantitative and qualitative data are used which reveals a complete overview of the topic from different sides. According to Saunders et al. (2012), it can be claimed that a mixed method was applied in this research. This method enables a better comprehension of the theme as well as its deeper analyses because the outcomes received via various methods can influence each other and lead to new findings.

Strategies

Triangulation of multiple sources was used in this study to ensure the fidelity of the outcomes found. It means that within this work different techniques of data collection were utilized. The chosen strategies for the current studies are represented in the triangle below and described in detail later in this chapter.

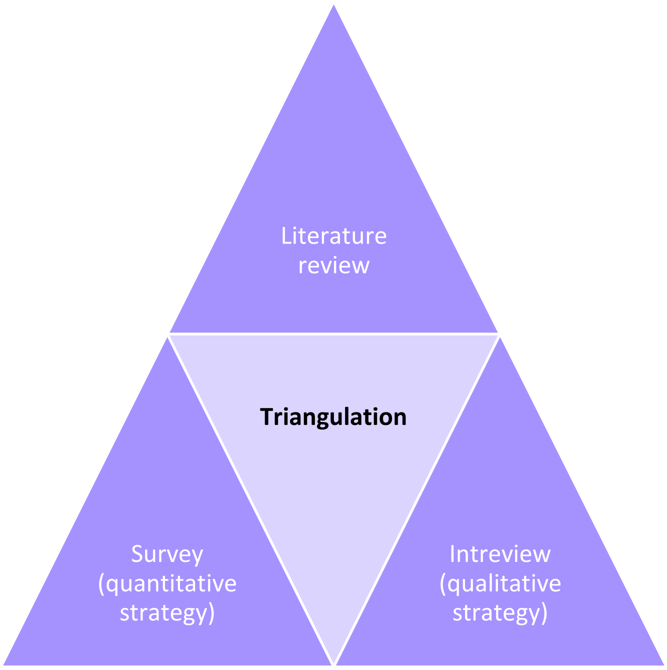

Figure 10. Triangulation model for research

Moreover, the author was able to have a personal observation of the technology that allowed one not only to understand the way of AR functioning but also to assess it from both technical and ergonomic sides on one's own.

3.2 Sample

Saunders et al. (2012) urges the usage of sampling, i.e., considering the collection of data only from a certain group of people since surveying the whole population will be both impractical and what is more likely impossible because of resources constraints. There are two main sampling techniques: probability or representative and non-probability. For the survey conducted during this research, the former one is employed because the representative sampling method allows one to make conclusions and answer research questions with the help of the chosen sample. The sample frame for the survey was defined as bachelor's students. Although the selection was not based on demographic factors, the country of origin, sex, and age were asked from respondents since this data was seen as valuable during further analysis. The number of people who received the survey was equal to 250. However, there were only 86 responses. It is crucial to count the response rate for the research since the lower the response rate is, the higher the possibility is that the information obtained is biased. The formula and calculations can be found below.

$$\text{total response rate} = \frac{\text{total number of responses}}{\text{total number in sample} - \text{ineligible}}$$

Figure 11. The formula of total response rate (Saunders et al., 2012)

The response rate of 34% for the student online survey can be considered appropriate for analysis and further conclusions relevant to the research.

As for the interview, special sampling techniques also were used. Firstly, a sample universe was defined by the next inclusion factors: man/women with obtained postgraduate education and work experience, work in/with AR and/or manufacturing-related areas, preferably prior experience with AR technology, possession of information about the technology usage inside the companies. The sample size for the current work was limited from 4 to 15 people since the information gained from such several people suits the purposes of a bachelor thesis. As for the strategy, a purposive and convenience sampling strategies were utilized. The former strategy implies that only those respondents were reached who, in the author's opinion, had knowledge about the subject and could contribute to it. Convenience strategy refers to relatively easy access to the participants and their willingness to take part in the interview. Thus, the researcher had confidence in the fact that one can reach the needed people for the interviews (Robinson, 2013, pp. 25-35).

3.3 Data collection and implementation

In order to do proper research, there is a need of gaining valuable and credible data and analyze it. This collected data can be either primary or secondary. This work uses both primary and secondary sources, and as was already mentioned it utilizes mixed methods. It includes different types of data for a better understanding of the topic and the possibility to answer research questions. Primary data refers to the new information that was collected by the author on one's own. The secondary data, it refers to already existing sources which are found and critically analyzed to get profound knowledge base of the topic, understand what has been already explored before and where there are still gaps (Saunders et al., 2012). In this subchapter data used for this thesis, its sources and ways of collection are described in detail.

3.3.1 Secondary data

At the very beginning, secondary data sources were carefully chosen, read, and critically reviewed. They helped an author to familiarize oneself with the chosen topic, narrow it down and prepare thoroughly for the interviews and survey. The main secondary data sources utilized in this work are demonstrated in Figure 12.

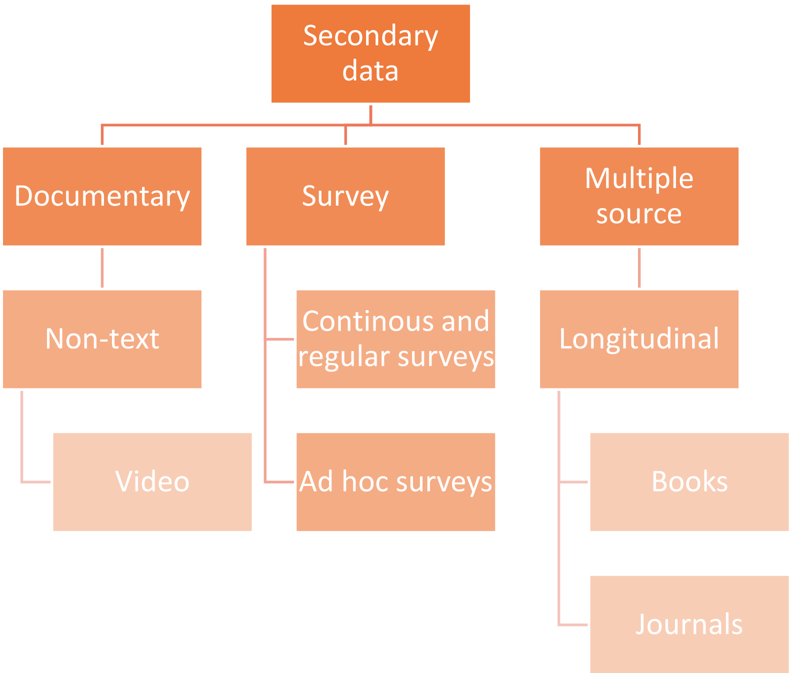

Figure 12. Secondary data sources (modified from Saunders et al., 2012)

Regarding secondary data, it is very important to mention here that even though a prevailing number of it is articles and surveys from credible sources such as Google Scholar, Science Direct, Scopus, Elsevier, and IEEE Xplore, there was also a necessity for using a substantial number of commercial websites and YouTube videos. This need was caused by the very essence of the work because it scrutinized the real-life practical application of AR technology in manufacturing companies. Although such cases are mentioned and described in academic articles, a wider and more precise explanation of projects is available only via commercial sources, hence via the websites of companies or videos produced by them. However, the author tried to take only objective information from these sources without adding any extra advantageous sides to the technology since a product is always presented in a better light by commercial actors than it is.

3.3.2 Primary data

As was already mentioned, interviews (qualitative) and a survey (quantitative) were used as primary data sources. Moreover, an author had a real-life experience with AR to assess technology on one's own and immerse into the field of the research better. In this section, the design of interviews and surveys as well as data collection is described. The description of the author's observation is also described.

Interview design and data collection

Interviews are considered the main method of gaining primary data for this research because the area of Augmented Reality application in smart manufacturing is a very specific one, and knowledge can be gained only from the experts in this field. Thus, they were conducted before the survey and are meant to be prevailingly relied on.

The process of interview design and data collection consisted of several steps and was thought through carefully because there was only one possibility to speak with a person. Therefore, the maximum amount of relevant for the work information should be gained during interviews. Figure 13 shows the stages of work on the interview creation, its implementation and conclusion.

Figure 13. Process of interview design and data collection

Before starting to create interview questions, one needed to obtain profound knowledge of the theme of research for questions to appear, to understand the themes that need to be covered during the interview and to be able to support a conversation with an expert. After the studies of secondary data, the most crucial aspects which would be examined during the interviews were chosen. They became the solid ground for the future questions.

Afterward, the first draft of interview questions was created. It comprised open, probing, and closed questions to get different kinds of information. Moreover, the semi-structured form of the interview was chosen. Although it requires a prepared list of questions, this model allows more freedom during the interviews when and if needed. Questions can be changed in order or context depending on the respondent or his/her answers. It brings flexibility to the interview and the possibility to gain maximum relevant information from different experts which is very helpful for this research since various parties are included in the interviews (Saunders et al., 2012).

Since it is impossible to test an interview with an expert because of the value of their time and difficulty to receive acceptance for the interview in general, the interview questions were tested with the help of other students. It helped to improve and 'polish' questions, remove not relevant ones, add the ones that were not included and to understand the timing of the interview.

After questions for the interview were ready, the most important part was left – to find experts who are willing to share their experiences and thoughts. It was a rather complicated task since the chosen theme is very specific, and access to professionals in this area is very limited for a student. However, by web searches, university, and personal connections, it was possible to find respondents who are directly or implicitly connected with the sphere of AR application in manufacturing. During this search it was crucial to try to find actors who are connected to AR from different sides, implying that it should be producers of AR hard- and software, companies and workers who utilize these devices, and other external interested parties.

The request to become an interview respondent and detailed information about the conducted research and requirements from the respondents were sent by e-mail and outlook to 18 people. 8 of them responded that the current theme is interesting for them, but it is outside of their competence, therefore, it would be impossible for them to lead a conversation about it. There was no feedback from 4 of them. Thus, there were 6 interviews agreed upon at the end. Different time slots and a place were proposed by the interviewees. All interviews were non-standardized one-to-one. However, the mean of connection varied depending on the expert's preferences. There is a list of respondents below, as well as the mean of conversation with them and their connection with the AR technology:

1. Expert A (face-to-face interview): teaching of 'digital technologies and digital solutions', creation of XR filming studio system, manager of the project aiming to apply XR technology in educational fields as well as in local (Finnish) medium and small-sized enterprises;
2. Expert B (face-to-face interview): working in different industrial positions, teaching of 'New technologies'
3. Expert C (face-to-face interview): IT alumni, technical specialist, programmer and game developer, creation of VR game, manager of the project aiming to apply XR technology in educational fields as well as in local (Finnish) medium and small-sized enterprises;
4. Expert D (Internet-mediated interview): researching AR in the 1990s, CO-founder of the AR Software company;
5. Expert E (face-to-face interview): lecturer of the asset management and maintenance;
6. Expert F (Telephone interview): international expert of AI, General Director of the company in the sphere of R&D in automatization of technological and business processes.

Since the background and experiences of experts varied noticeably, the list of questions should have been modified slightly to comply with the expert field. However, the essence of the questions always remained the same so that analyses of the acquired information can be carried out. The sample of questions can be found in Appendix 1.

The next step was to interview experts. The time needed for one interview was estimated to be 1 hour. Practically the time varied from 20 minutes to 1 h depending on the extent of the expert's knowledge regarding thesis specific theme. A few words for the introduction and conclusion were said to focus the conversation on the specific theme and to define the end of the interview. All experts were asked at the beginning about their desire to stay anonymous or not and the permission to record the conversation. All interview questions can be divided into subtopics, starting from more personal and general questions, continuing with more field-specific ones, and finishing with the offer to add some open comments (see Table 2).

Table 2. Interview questions structure

Question	**Theme**
Questions 1-2	Personal background and connection with the research topic
Questions 3-4	Smart manufacturing and AR concepts and their role
Questions 5-6	Present-day AR application in manufacturing
Questions 7-10	Challenges and future perspectives of AR application in manufacturing
Question 11	Additional comments

Finishing the interview, each of them was transcribed and the most important points were chosen. It led to the next two steps:

1. Making conclusions about any changes to the author's research since new issues and ideas were raised during interviews;

2. Changing and improving questions for the next interviews since only real-life practice can show what questions are good and which ones should be altered/removed.

Step 11 brought a researcher back to step 8 (interviews) till there were no more respondents. After the results and crucial notions of all the interviews were revealed, the author started to make comparisons and findings which are presented in chapter 4.

Biases during interviews and their avoidance

There are a lot of possible biases which can appear in the process of creating interview questions, during the interviews themselves or while their analyzing. The next biases that are emphasized by Saunders et al. (2012) were taken into consideration in this research while gaining primary data through interviews:

1. *Interviewer bias*
   It refers to the biased behavior of the interviewer him/herself which influences an answer of the respondent, for instance, while asking questions with a specific intonation or putting the accent on something because of one's own beliefs and desires. Moreover, the analysis and interpretation of the given answers are also viewed through the interviewer's prism, thus, can be understood and explained differently from what they were supposed to mean.
1. *Interviewee or response bias*
   It is connected to the unwillingness of the respondent to reveal some sensitive information or answer questions they are not allowed to or that will show them in a socially undesirable way.
2. *Participation bias*
   Since participants have to spend time on an interview, it can lead to the denial of certain people to take part in it. Thus, a sample from whom data is collected can be biased and not consider other opinions.
3. *Generalizability*
   This issue is related to the avoidance of generalizing facts too much, especially while having not a big number of respondents since such a set of information includes only some opinions of specific individuals, not meaning that everyone in their position thinks like this.
4. *Validity*
   The possibility to gain enough deep information from the respondents and interpret it correctly is regarded as a validity of the research.

Survey design and data collection

Primary data in this research was also collected with the help of questionnaires. Although the main focus was made on the expert opinions obtained via interviews, it was thought that a survey aimed at students could help to better understand the future perspectives of the technology since those who are currently studying at the universities are the future workers. Thus, it is precious to understand their familiarity with AR and their readiness to utilize it.

For the above-mentioned purpose, a self-completed Internet-mediated questionnaire was created via Google Forms. It was anonymous and covered research-specific questions but explained and asked them in a simple way so that respondents can realize what they are asked about, and give a credible answer (Saunders et al., 2012). Figure 14 represents the flow of work on the survey. Explanations on each step are provided after it.

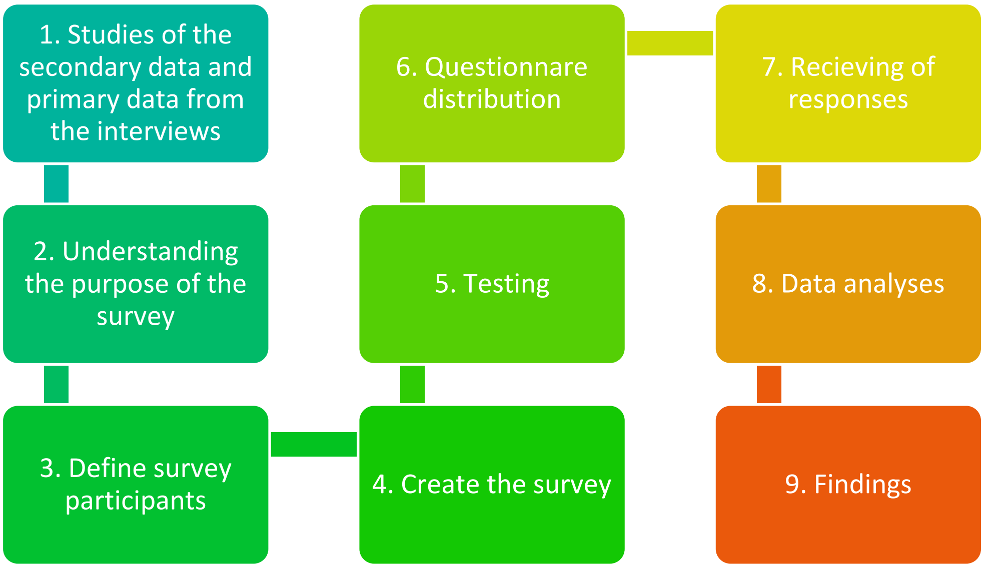

Figure 14. Process of questionnaire design and data collection

Before creating a survey, the author already had a profound knowledge of the topic since secondary data sources were studied, interviews were held, and their results were analyzed. It was necessary to do so for two reasons:

- As was already mentioned, a survey was a second by importance source of primary data;
- To be able to explain and ask questions about the topic in simple words, one needs to understand it deeply and see the problem from different viewpoints.

Moreover, the author had to define the purpose of the survey and understand if there was a need for it. As it is stated above, the aim of the questionnaire was to acquire a better image of the future of the technology by questioning future talents who will work with this technology the most. Therefore, it helped to answer the second and third research questions and consequently added value to the research objective.

All participants should have been bachelor's students, more preferably if they are from different countries, programs, of different sex and age because it allows us to gain a comprehensive outlook of the issue and define patterns. That is why demographic data was asked from the participants.

Step 4 was the creation of the survey itself. It constituted open questions (for example, to ask about the role model companies that utilize AR), list (e.g. to define the most meaningful challenges), category (e.g. for the age), rating (e.g. to assess the willingness to work with the technology or trust in it), and multiple-choice questions (comprise the biggest part of the survey to facilitate responding) (Saunders et al., 2012).

Besides, the survey had a logical order and included an introduction, main part, and conclusion. At the very beginning of the questionnaire, participants can get familiar with AR technology and watch a short video about it. Required time for the survey and information about data and its usage were also explained there. Moreover, a short introduction was added before the subsection with questions about AR applications in smart manufacturing for the participants to gain a better understanding of the theme. In the end, all the respondents were thanked for their participation.

The main part was divided into sections and moved from more general questions to more specific ones (see Table 3). It was considered that participants of the survey had either a very vague understanding of the theme, a good one or not at all. Therefore, the questions were created in a way that everyone even without any prior knowledge can answer them. The survey consisted of fifteen questions and took 5-10 minutes. Since normally people are not willing to spend time on surveys, the most accurate and valuable questions should be asked in a short time and well-presented form. A ready questionnaire form can be found in Appendix 2.

Table 3. Survey questions structure

Questions	**Theme**
Questions 1-4	Socio-demographic background
Questions 5-7	Presence of prior knowledge about AR
Questions 8-14	Research-related specific questions about AR application in manufacturing including imaginary scenarios, questions about possible challenges, future perspectives, and general trust in the technology
Question 15	An open question for extra comments

In terms of testing, surveys are easier than interviews since one can test it with any person. In this case, the one who does not have any connection to the theme is a better candidate for testing since s/he will be able to help to make a survey as easy and understandable as possible. Three students, whose responses were not considered at the end, were chosen for testing. It helped to define the time needed for the survey, modify and enhance questions, and asses the real value of the data asked. In general, a survey was changed considerably in terms of formulations, its content, level of difficulty, and subtopics.

After all these stages, a prepared survey should have been distributed. Different social media networks and platforms were used for this purpose (because students are easier and faster to be reached there): Instagram, WhatsApp, Telegram, and VK. When a sufficient number of respondents for the bachelor thesis was achieved, analysis of obtained data was conducted, correlations were found out, interesting and notable remarks were done, and respective findings were made. All these results are as well presented in chapter 4 'Results from the Collected Data'.

Survey biases and their avoidance

The creation of well-structured and thought-through surveys is a complicated task. Considering and avoiding some biases is one of the objectives that can improve the credibility of the survey.

Lugen (2015) stresses the most crucial biases to be avoided during the process of work with questionnaires that were also considered during the current research.

<u>*Cognitive biases*</u>

1. *Framing effect:*
   This effect implies the influence of the context in which a question is asked and its influence on a respondent's answer. It is almost impossible not to have this impact on people who answer survey questions, which is why the questionnaire creator should be aware of the framing elements and effort to make them homogenous throughout the survey.
2. 'Halo' effect:
   Human-beings' perception is more structured than analytical; hence it tends to grasp sets of information by evaluating them in relation to each other. It means that a certain modality of questions will always lead to the same responses from different people. It is why it is important to interrupt this sequence by, for example, open-ended questions.
3. *Priming effect:*
   It appears when a previous question brings a specific meaning to the following question and causes another biased answer.
4. *Positivity bias:*
   People are in general inclined to answer positively than negatively. It is crucial to avoid this bias by avoiding a lot of questions with binary responses and, for instance, adding bipolar scales where a person has to choose an extent of disagreement or agreement.
5. *Memory bias:*
   For a person in order not to forget what was asked or mentioned a few questions ago, it is important to bring reminders of the topic and its main aspects. For those ones who have difficulty focusing on all the elements of the question (short-term memory), the questions should be simplified and shortened as much as possible.

<u>*Motivational biases*</u>

1. *Commitment bias:*
   This bias relates to the tendency of people to remain consistent in behavior or answers. It can make a person stand for the opinion that corresponds with the one that was stated or defended before even though this opinion does not belong to the human him/herself. Thus, syllogisms should be avoided in surveys.
2. *Social desirability bias:*
   Simply stated, it is a bias caused by the desire of human nature to give a positive image of oneself by one's answers, consequently, to embellish some facts about oneself (pp. 7-8).

Author's observations

Expert C agreed to let the author experience utilization of AR glasses in real life. Such an opportunity of having a real-life observation of the technology at which the whole research is aimed at was considered very valuable. The main purpose of this observation was to gain a deeper comprehension of the technology and to try to reveal its advantages and drawbacks in usage. Moreover, it was set as an objective to assess AR functioning and its ergonomics and to create a more solid personal opinion about Augmented Reality, its present, and future.

The testing took place at the digital and game center in Finland. The models of AR devices used during the observation were the first versions of Vuzix AR glasses and HoloLens. The systems and their way of functioning were explained by the expert. The author was able to wear glasses, see their home screen, options, and with HoloLens it was possible to try some game applications which provided 3D models and sounds. It was possible to move objects with hands and to manage the system with both gestures and sounds.

A lot of useful for the research information about the glasses and their usage was also obtained during this meeting such as real-life application of AR in companies, improvements, and developments of the next versions of AR glasses, detailed overview of the technology and its components. All personal findings derived from this observation are described in the next chapter.

Figure 15. Author's experience with Vizux and HoloLens

3.3.3 Research implementation

Every research should have a solid plan to follow so that data is collected in a logical order and wisely (see Figure 16). Gain of new knowledge must help to proceed with the research further.

The work fundamentally started in November 2021 by defining the main topic, gaining knowledge about it through already existing works and present-day news, and then narrowing it down since by having a too wide theme, it becomes harder to write research on point with valuable information that can fit into the Bachelor thesis. Objective and questions for the research were also defined for the further proceeding with the work by finding answers to the defined questions. Therefore, the research methodology was defined, and it was decided to apply the triangulation method. The first step to be done was a thorough literature review that was already selected and aimed to answer research questions. Interviews and survey were designed and implemented in March-April 2022. Testing of the technology in the real life also took place during the latter month. The information was collected fast enough, and the next two months were spent on its careful analysis and studies of the results. After all this work, July and August of the same year were spent on the final steps such as making conclusions, responding to the research questions, assessing the work, and defining its limitation and future research possibilities.

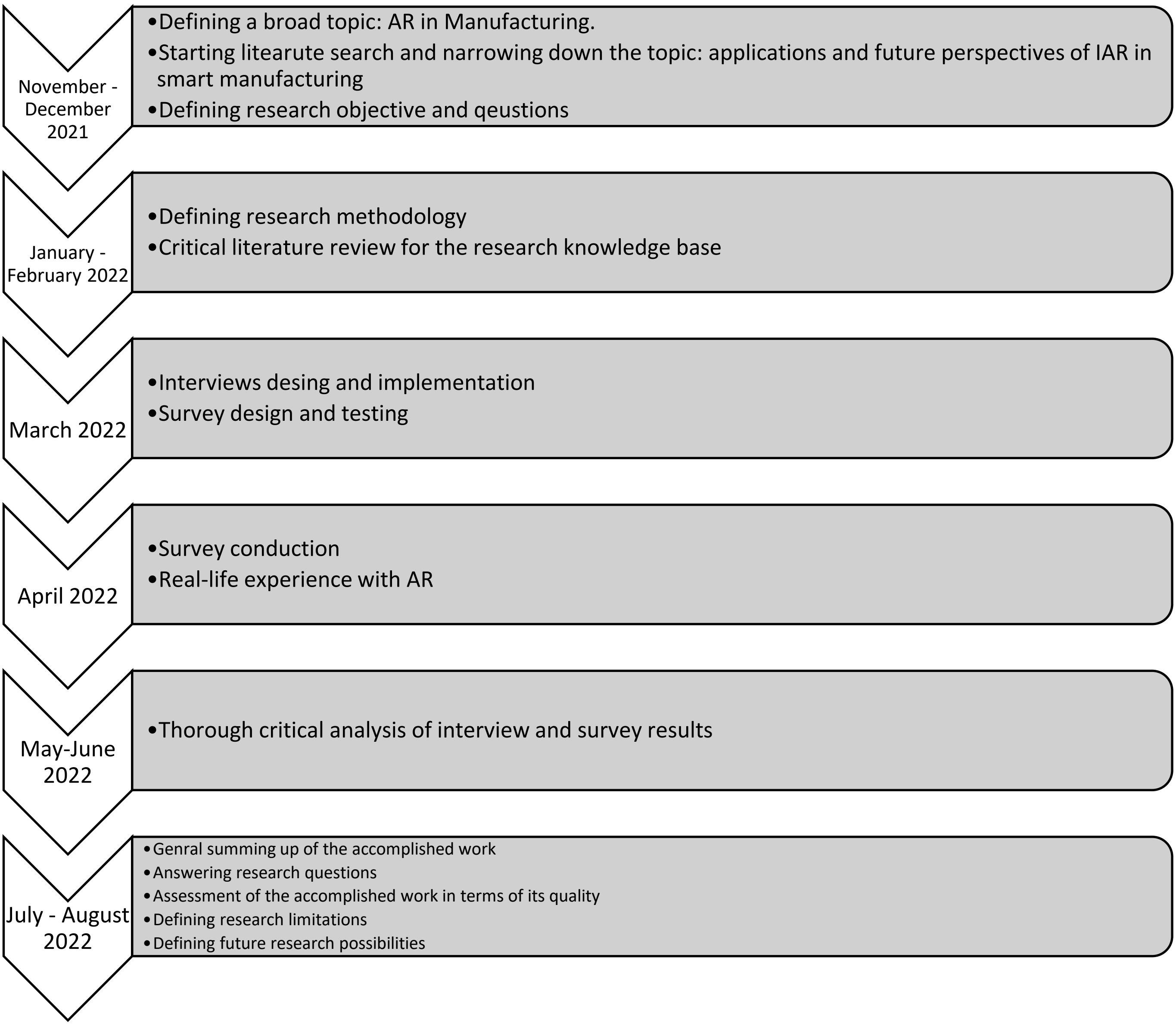

Figure 16. Research implementation

3.4 Data analysis and interpretation

Interviews were recorded, transcribed, and analyzed by the author on one's own. The most important interview findings were represented in tables by themes so that the answers of different experts can be easily compared. After each table interpretations of the interview citations and their summary are provided.

As for the survey, it was analyzed with the help of Google Forms and Excel which allowed to understand a common students' awareness of the technology. Besides, SPSS Statistics was utilized to reveal correlations between obtained data and gain its deeper analysis. Survey results were represented both descriptive and visually in graphs and tables.

3.5 Plan for the research quality and ethics

Saunders et al. (2012) claims that every research should follow ethical rules in terms of collecting both secondary and primary data. This rule applies even more to research in business areas because they are almost inevitably connected with the human engagement (e.g., interviews, surveys, observations, etc.) and consequently obtaining of data about them and from them. Moreover, the issue of privacy and collected data has been brought even more into the spotlight in the last decade. That is why it is crucial to know how to gain access to the data correctly, how to treat respondents and information received from them, and what else should be considered.

The plan of gaining data and its usage was created after defining and narrowing down the topic and before starting the work. The main guidelines developed for this work are mentioned in the list below:

1. A researcher is objective and honest in one's research
2. Rights and dignity of other people are respected, as well as no harm is caused to them
3. Privacy of participants is to be respected by the next means:
    - Informed consent about the participation in the research project is provided
    - Participation is voluntary
    - Confidentiality and anonymity are ensured
    - Participants are aware of data collected or recorded and the way of its usage
    - Questions about gender and age in the survey are not obligatory to answer
    - There are no questions that can raise and aggravate the issues connected with gender, nationality, religion, politics, and other delicate topics
4. A researcher takes responsibility for thorough analysis and objective interpretation of findings
5. A researcher takes responsibility to provide quality research with credible sources of primary and secondary data

As for the secondary data, it is also worth mentioning that information is cited and referred to in accordance with the APA rules anti-plagiarism. All authors and their rights are respected, and information taken from other sources is not distorted from its original.

4 Results from the Collected Data

This chapter provides insights into the findings from the primary data: interviews and survey. The most important and meaningful conclusions are highlighted here. Since the purposes of these methods of data collection were different, they are analyzed and discussed separately.

4.1 Interview analysis and findings

Interview analyses are presented in this subchapter. The most important abstracts were chosen from all the interviews to bring understanding of experts' opinions about the research theme. Results are divided by topics and demonstrated in tables so that it can be visibly easy to compare notions of six different respondents. The four topics were chosen as central ones for analysis: manufacturing processes gaining maximum benefit from AR, the extent of AR applications nowadays, current challenges of AR and needed changes, and future perspectives. Conclusions and comments of the author are provided after each table.

Table 4. Interviews: manufacturing processes gaining maximum benefit from AR

Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
'The best thing that you can do with AR is to make see things that you normally cannot see' 'You can test everything before you actually build it	'Guidance and teaching of new employees… and decrease of quality defects.' 'AR can show something that is invisible in your eyes.'	'In assembling, if AR is built in your glasses, it allows you to get a lot of information about the assembly process, … your hands will be free to do the assembly. You	'… employee training, maintenance, logistics, real-time reporting, product design, quality inspections …'	'I personally did not find a place where you have a worker that needs information and AR will not contribute to that.'	'This technology is especially useful in the construction and product design processes, training of personnel in dangerous

[with AR and Digital Twin].' 'You have the virtual version of the assembly line, and you can make the training for the new workers very easily… for example, in the work with nuclear reactors' 'We do not need to send anymore a guy from A to B. There can be a person there [in place B], who does not even know these things so well… Sending people is time-consuming and expensive.'		do not have to look from the device with instructions to the assembly line again and again.' 'If a person has to assemble something, he did not assemble yet, then he can use guidance from AR system.' 'A technician can read the bar-codes and choose the right detail to put into the assembled product.'			working environments, maintenance, and quality control'

All experts found areas of manufacturing to which AR technology can contribute and bring benefits. The most prominent examples of AR application such as training or (tele)maintenance were mentioned, as well as some new examples of the usage of Augmented Reality, which were not covered in the literature review of current research, were named, in particular, the possibility of AR showing processes invisible to human eyes (machine functioning, cables in the walls) or product design. However, one of the most important conclusions that should be done from the above-mentioned answers is that there are definitely various existing manufacturing processes that AR can bring advantages to.

Table 5. Interviews: extent of AR applications nowadays

Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
'Companies do not use this technology. You can find a lot of videos on the Internet, but it is still not a very common technology' 'There are already some success stories, but there are still quite a few'	'There are more or less pilot projects, not actually standard applications'	'AR is not as widespread as VR, and even VR is not yet a household thing.'	'In company X, all maintenance workers use AR glasses.' 'Car-manufacturer Y uses it for product designing and virtual crash tests.'	'The companies today are more aware of the technology than 5 years ago.'	'It is still not mature enough, but already started to be integrated actively.'

It can be said that although experts made not exactly the same statements, their meanings can be summarized as follows: although manufacturing companies are much more aware of the AR technology nowadays than in the past, and there are already examples of successful pilot projects or real-life AR applications in manufacturing processes worldwide, the technology is still not mature enough and should be enhanced significantly before it starts to be utilized massively and to bring considerable benefits for companies.

Table 6. Interviews: current challenges of AR and needed changes

Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
'People tend to hang on the old-fashioned things that we have prepared, for example, some PDF files from where we can read the instructions.' 'We are hoping to create dialogues between companies and educational institutes because the former ones do not have the knowledge.'	'Unfortunately, there is a lot of need in development: networking with the devices, more sophisticated and comfortable materials to use from the point of employee …, and communication in real time' 'Knowledge and practical solutions [are missing]. It might be hard for companies	'There are no ready-made solutions that are easy to tailor for different use cases.' 'The hardware is the biggest limiting factor. It costs a lot of money, and it is usually not compact.' 'Another issue is security and integrating with other systems from	'Many people at the companies do not understand the possibilities of the technology' 'Before it spreads widely, it should be proved effective.' 'Knowledge and need of innovative minds …' 'It costs a lot: one needs to educate people, invest in	'There are two tracks: hardware and software. As for the hardware, we still wait for good devices that will fit workers better: bigger screen size, better sensors, better ergonomics... From the software side there should be a lot of integration work on the shop	'A human-being is more trusted nowadays than a machine' 'When the performance efficiency will be counted not by minutes, but by seconds, companies will realize that AR can accelerate manufacturing process efficiently.' 'Scare of control of the

'The knowledge should be more shared… For example, most of the people do not really know what XR technologies actually mean. They think it is a game.'	to understand how these solutions can help them.' 'A new technology … might be a little bit scary. Employees might take it not so happily.' 'Taking investment into a new technology, you are not fully sure what will come out of it.'	the manufacturing process.' 'If there is no demand for AR – there will not be any ready-made solutions, but if there are no ready-made solutions – there will be no demand.' 'One will face resistance because no one likes changes.' 'Management should be convinced that they need AR, and then the workers of assembly lines also should be convinced.'	equipment and whole working processes have to change.' 'Visibility is a problem due to small displays'	floor. There is also a lot of work on the OS level.' 'Management has to realize that the technology brings improvement, … and then technology should be accepted by the workers as well.' 'Management sees that they have to work too much at the beginning, and they get scared.' 'It is scary that most of them invested in digitalization, and now they see that they	processes by technology.' 'Ergonomics is not good: too heavy and big. It is hard to constantly wear glasses.'

		'The biggest issue for smaller companies is the cost.'		have to invest again in AR.'	

As can be observed from all the comments given by the respondents in terms of challenges that hinder AR integration in manufacturing and respective changes needed to be implemented, AR systems are still not in a very stable position. There are a lot of factors that prevent or can prevent companies either to integrate the technology or even to have a desire to do it. All issues mentioned by experts are summed up in the list written below:

1. *Lack of knowledge*
   Companies are not conscious of the way of using the technology and advantages it can bring. It is necessary to demonstrate ready-made solutions for existing problems so that companies realize why they need this technology and what it can change. Till management and workers do not accept AR, it is impossible to integrate it into manufacturing.
2. *Hardware and software*
   This aspect of AR systems is still very weak. There were a lot of critics from respondents in terms of hardware and software, starting from not appropriate ergonomics to the lack of standardized software solutions.
3. *Fear of workers and management of uncertainty*
   Since there is a lack of knowledge, both managers and workers have bias about the trust in technology for their manufacturing processes.
4. *Investment risk*
   The previous problem is logically connected with this one: being concerned about the technology itself, company would not want to take a risk of an investment that they are not sure will bring any payoff in the future.
5. *Unwillingness of changes*
   AR brings a lot of changes meaning that management and workers need to refuse previous ways of working that they are used to and put effort to get used to new principles. Most of the companies will not be willing to do it.
6. *Security issue*
   Some experts also raised the question of security. Integration of some outside systems into the inside industrial processes can bring concerns to manufacturing companies.

Table 7. Future perspectives of AR

Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
'It is going to take some more years, but I am sure that these things [AR] are going to be a reality quite soon because now it is technologically possible, and it is not expensive, but of course, you need also the knowledge.' 'What I have heard it is from 3 to 5 years. Things should be better and used in more companies.' 'When social media companies start to use things,	'It is hard to estimate how long it will take to be as a standard, but it definitely will be more common in a couple of years.' 'Of course, universities should spread the word, but mainly the companies who are providing AR services and solutions should be more active to find actual practical cases.' 'There are so many new technologies	'There is a lot of potential in Augmented Reality.' 'If people have already used this technology at school, it is much easier to adopt to it when they start working.' 'In 10 years, it will be much better already.' 'Entertainment industry has a huge amount of money. If someone there starts making money with AR, then other companies will start	'We have to teach the students, and when they go to companies, they spread the knowledge about technologies.' 'Government has a lot of development projects; they can emphasize the role of this technology.' 'Technology is quite ready for effective applications, but the companies do not see the possibilities yet.' 'In general, it will happen sooner or later when there will be a lot of	'It [AR] is mature. There are still a lot of improvements to be done, but it is there to stay.' '…mass integration will happen in about 5 years…' 'We will see in 3-5 years a lot of improvements in 5G for industry, so the communication side of AR will improve.'	'In the future AR glasses will evolve into AR lenses and projection of the images into the brain.'

things get normal and then business follows’	on the megatrend, I am not sure how well AR technology will overpass those technologies.’ ‘Digital Twins combined with AR might give the needed step where AR will become more common’	using it. Then there will be more solutions, more advanced technologies and more software developers.’	good solutions and applications.’		

The last aspect that will be discussed in the interview analysis is the future perspectives of AR. It is apparent that opinions of different people in terms of further AR development varied. Although some doubts about the future of AR can be observed in the responses, it can be noticed that none of the experts foresee stop of the technology’s progress continuation. In general, respondents evaluated a better positioning of AR and its massive integration in 3-10 years. Most of them also stressed that a technology is promising and with the right improvements can contribute to manufacturing a lot.

Another question that was of great interest to the author was at which level changes should start. The next answers were provided:

- *Educational institutions*
  By getting familiar with AR at schools and universities and being able to use it, it is highly likely that

the technology will start being integrated into manufacturing because the young generation will come to work with knowledge about the technology and its possibilities for improvements.

- *AR production companies*
  Some of the experts were assured that the companies who produce AR hard- and software should bring not only the technology, but also the knowledge to the companies.
- *Government*
  One respondent mentioned that the support of technology by the government will change the companies' opinion about it and make them consider the technology since the benefits will be emphasized by the higher authorities.

Besides, an interesting notion was discovered during the interviews: some experts supposed that the future development and deployment of AR in manufacturing will be pushed by the entrainment industry. They assumed that this industry brings megatrends and makes not only people, but other businesses also follow them. Consequently, a rise in AR popularity in social media or gaming will accelerate its integration into the manufacturing industry as well since more people will be aware of it, more solutions and system creators will appear.

Therefore, interviews with people related to Augmented Reality by different means brought a lot of new notions about the research theme, its broader and more comprehensive overview, and the current state of AR since it can be truly understood only by communication with people who have access to the relevant information. Moreover, gathered opinions and their critical analysis made a considerable contribution to answering research questions.

4.2 Survey analysis and findings

In this subchapter, a survey and its findings are revealed. The results representation is divided by blocks likewise it is asked in the questionnaire. An author tried to get a general understanding of awareness of the technology and readiness to work with it of the future talents, i.e., current students without deepening too much into the topic itself because in this case the more difficult and profound the survey is, the more there is the possibility of getting less credible results. It could happen because of non-understanding of respondents what they are asked about or unwillingness to answer long hard surveys. For the same reason not all fields of AR application were included in the survey and only some imaginary examples were used. Some captivating revelations are presented at the end as well.

Before analyzing, it is important to mention that survey results can be considered credible enough for the Bachelor thesis because the respondents' sample was rather heterogeneous in terms of:

1. Study fields (with the prevailing 53.5% of business students, 10.5% - engineering and 9.3% in IT)
2. Gender (51.2% - female, 48.8% - male)
3. Country (with the biggest number of respondents from Russia and Finland – 29.1% each, and France 9.3%)
4. Age (it is also regarded as not homogenous because only students were surveyed, however, there are 14% of people 26-35 years old and 2.3% of 36-45 years old)

Students' awareness of the technology

The question that interested and the author is whether students at least have heard about the existence of such technology. It should be understood that it does not imply that they know what it is or how it functions, it just relates to the fact that they heard it from someone or somewhere in their life.

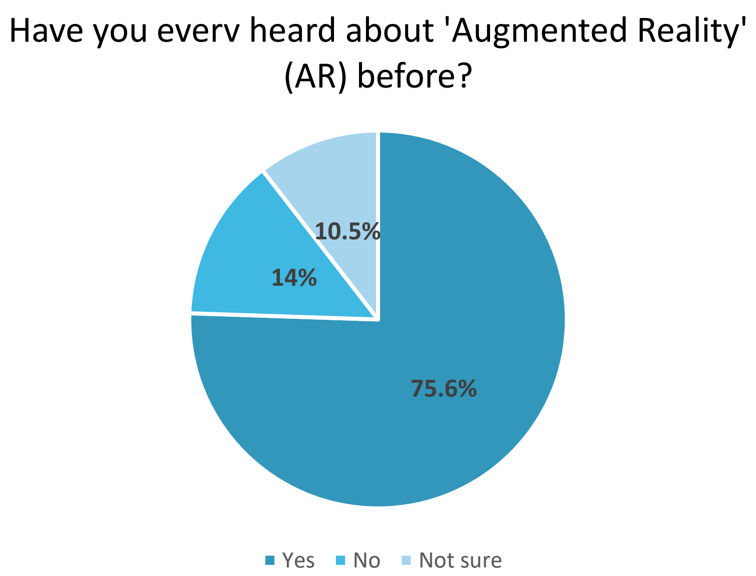

Figure 17. Survey: AR awareness

Although it can seem that having almost 76% of students who have heard about the technology is a lot, one should try to analyze by contradiction: 24.5% of students either have never even heard about AR existence or are not sure that it was this very technology. Since the sample was with the prevailing numbers of students in certain study programs and from certain countries, it was thought to be not credible to try to find connections between the absence of knowledge and any other demographical parameters.

Nevertheless, we can try to find if there is any connection between the gender of students and knowledge of the technology. To understand it, Chi-square test carried out in SPSS, one of the analyzing methods mentioned and explained by Garth Andrew, will be used. It allows us to find out if variables are correlated with each other, as well as shows what the observed results are and what would be the expected numbers if there was no relationship in the sample.

The first step to be done is to define null and alternative hypotheses to either confirm or reject the former one after finding out the results.

H_0: There is no relationship between the gender of the student and their awareness of AR.

H_1: The awareness of AR depends on the gender of the student.

The results of the conducted test are represented below.

Table 8. Gender*Awareness crosstabulation

			Awareness			Total
			No	Not sure	Yes	
Gender	Female	Count	9	7	28	44
		Expected Count	6,1	4,6	33,3	44,0
	Male	Count	3	2	37	42
		Expected Count	5,9	4,4	31,7	42,0
Total		Count	12	9	65	86
		Expected Count	12,0	9,0	65,0	86,0

Table 9. Chi-Square Test

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6,981[a]	2	,030
Likelihood Ratio	7,285	2	,026
N of Valid Cases	86		
a. 2 cells (33,3%) have expected count less than 5. The minimum expected count is 4,40.			

Important information is represented in the row 'Pearson Chi-Square' in Table 9. The test revealed that the significance level of data is 0,03 ($p < 0,05$) and the Chi-square value ($\chi 2$) = 635.561, which leads to the conclusions that the null hypothesis can be rejected, and there is a rather strong correlation between the gender and knowledge of the AR technology (2008, pp. 62-64). It can be supported by and observed in Table 8 that the count and expected number of male and female students being conscious of AR vary noticeably. The data in Table 8 demonstrated that in the obtained data there are more female students who do not know or not sure they know about the technology, which allows us to say that male students are at present are more informed about AR. This finding allows us to guess that there is still a bigger proportion of men studying and interested in technologies of industry 4.0 and/or manufacturing than women. However, the difference between women's and men's awareness was not dramatic, out of which we can suppose that the fields of interest and studies of both genders have already overcome changes and are going to alter further.

It was also relevant to the author to understand from where such a big number of unawareness about the technology aroused and whether those ones who knew about it got this information from their own experience or educational institutions. That is why the question about the AR-related courses followed. As it is obvious that the existence of courses about Industry 4.0 (including AR) as well as personal studies about it will raise the awareness of students about the technology, there is no need for these variables to be proven. Crosstabulation is used to represent the relationship between the availability of university courses about AR and students' knowledge about it (see Table 10).

Table 10. Awareness*University crosstabulation

Awareness * University Crosstabulation					
		University			Total
		No	Not sure	Yes	
Awareness	No	10	2	0	12
	Not sure	6	2	1	9
	Yes	40	5	20	65
Total		56	9	21	86

It can be seen from the table that such a high level of ignorance about AR is caused by the unavailability of courses connected with AR at universities. Several conclusions can be made from these observations. Firstly, if there is no knowledge about the AR gained from universities, it is highly likely that students did not learn the subject of Industry 4.0 in general since this technology is one of its components, and it would with a big probability be mentioned even once during such a course. Secondly, remembering that 73.3% of respondents are either from Business or Engineering or IT studies, it leads to the notion that there is a negligible level of studies about technologies of the present and future in those spheres and for those ones that are explicitly connected with them.

It can be also observed that only 20 out of 86 respondents gained knowledge about AR from the university courses, whereas the other 40 ones knew about it from their lives and interests outside of the university which is equal to approximately 47% of all surveyed students. Apart from it, it can be noted that 20 people neither heard about the technology at educational institutions nor had any personal interest in it. There was one respondent who answered that s/he did not hear about the AR although one had a course about it at the university. This answer is regarded as invalid by the researcher since logically it is impossible.

The next revelation to be discussed before moving to a narrower research-specific question in terms of the survey is consciousness of students of the real-life examples of AR applications. Only sixteen respondents out of 65 who heard about AR systems named examples of the companies that use them in the manufacturing processes. On the one hand, it potentially gives a hint that even though there is knowledge of AR, there are not so many young people who know about its usage in companies. On the other hand, the questions and theme itself is rather specific and narrowed down, thus, it is not objective and correct to expect a high level of awareness, taking into consideration as well that there is still a percentage of people who are not connected with this sphere at all. Moreover, it should be perceived as already valuable and promising that some respondents knew about the companies connected with AR (although some of them related to the creation of AR, not manufacturing). A lot of different examples starting from Apple, Oculus, or Niantic to Boeing and Volkswagen were remarked by respondents.

Student readiness to work with AR and influencing factors

To gain an understanding of students' readiness to work with the technology two possible scenarios of using AR in training and tele-maintenance were provided. Also, the features that seem the most crucial for students in these situations were offered to choose or to suggest one's ideas.

For expressing an opinion about willingness to work with AR technology in a certain area, interval rating scale questions were provided where one corresponded to 'definitely would not work', and 5 to 'definitely would work'. It was not of priority to find out in which area (training or tele-maintenance) students are ready to work more, rather what the general level of students' willingness to work with the technology in the future is. Therefore, the mean of these two results was found and a new variable 'Readiness' to work with AR was created and analyzed in SPSS Statistics.

Figure 18 demonstrates a general readiness of current students to work with AR in the future in such areas as training and tele-maintenance. As can be seen from the chart although there are young people who do not show readiness to work with AR technology, the prevailing number of students have a positive inclination towards applying it at work. The majority of respondents (15,2%) assessed their desire of using AR in the manufacturing environment as 5, meaning they would like to work with the technology, 11,2% estimated their enthusiasm about this idea as 4, and only 1 student (0.6%) completely refused the fact of utilizing AR in one's work.

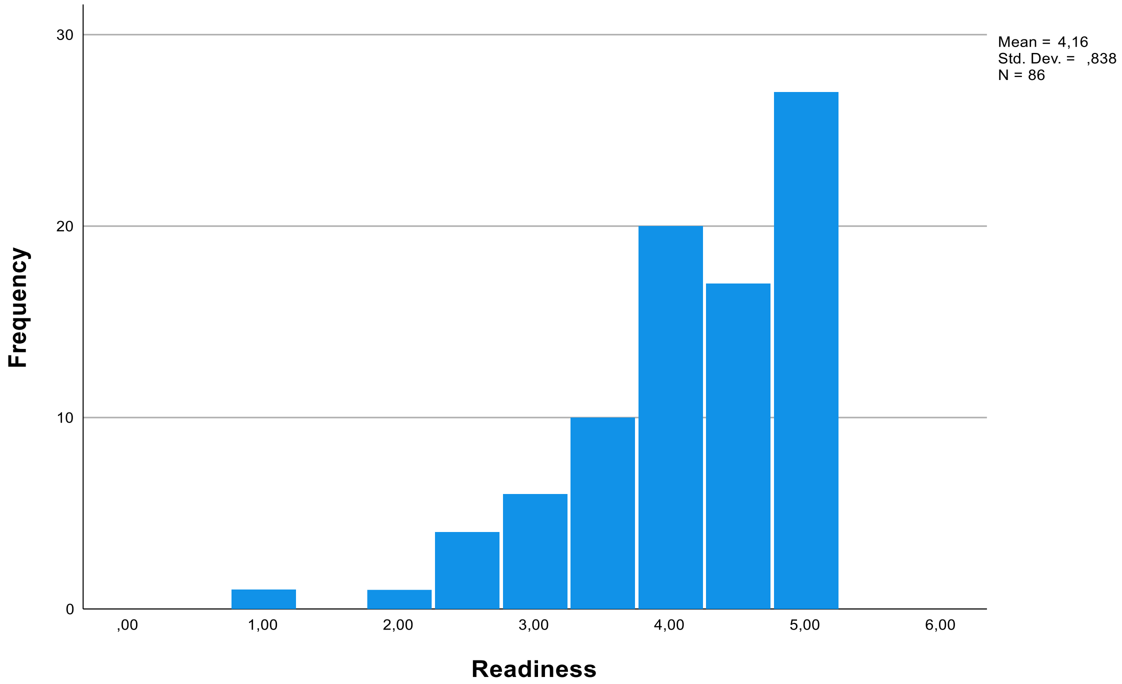

Figure 18. Histogram: students' readiness to work with AR

Another important statistical data derived from the analysis of students' readiness to work with AR devices is presented in Table 11. Different kinds of averages are found out to avoid misleading information and conclusions. As can be seen from the statistics, the central location of the data distribution (mean) is approximately equal to 4.2. It can be considered as a high point and level of readiness from the students' side. However, since the mean does not always manage to find the 'center' of data, especially when the distribution is more skewed, like in our case, it is better to apply and rely on the median to find an average. In this case median turned out to be even more than the mean, implying that a more correct assessment of young people's desire to use AR in manufacturing work is 4.5. As was already mentioned before, the most common value chosen by students was the mode of the data represents this fact one more time.

The last parameter to be analyzed regarding these two survey questions is the standard deviation. It shows how disperse the obtained data. The higher it is, the further data is from the mean. We could see that the greatest number of answers are concentrated around 4-5 values. That is why the deviation is only 0.84. It implies that the data is very close to the mean and has no extremes. It shows the consistency in students' opinions regarding the willingness to work with AR which can be regarded as a promising sign for the future.

Table 11. Statistical data on students' readiness to work with AR

Statistics		
№	Valid	86
	Missing	0
Mean		4,1570
Median		4,5000
Mode		5,00
Std. Deviation		,83758

It is also worth mentioning which features of the AR headset were considered crucial by students for the training and tele-maintenance objectives. Table 12 covers the top three features for each of these tasks.

Table 12. Survey: crucial features of the AR headset in different tasks

Training		**Tele-maintenance**	
User-friendliness	61,6%	Speed of processing	62,8%
Graphics	58,1%	User-friendliness	52,3%
Ergonomics	51,2%	Graphics	47,7%

As can be noted from the responses, user-friendliness and graphics are very important for students for both tasks. Young people stress that the technology should be easy to use and technologically well-developed in terms of graphical representation. However, it is worthwhile paying attention to a little change of one feature: two of the aspects remained the same as for the training task, but the first position was taken by 'speed of processing'. It can be explained by the fact that tele-maintenance includes the need for live communication with an expert. With a slow processing speed, it will be very hard to provide a proper connection and will take a lot of time to complete the task. Whereas training normally takes a lot of time and asks for a lot of new unfamiliar moves and actions, and not well-created device in terms of ergonomics would add extra stress and discomfort to the user.

Future of AR and challenges of its integration

Finally, students' beliefs about AR's future and doubts about it were necessary to be comprehended. Three main questions were raised: which areas of manufacturing will benefit most of all, how high is their trust in AR future development in manufacturing, and which issues prevent the technology from a successful deployment.

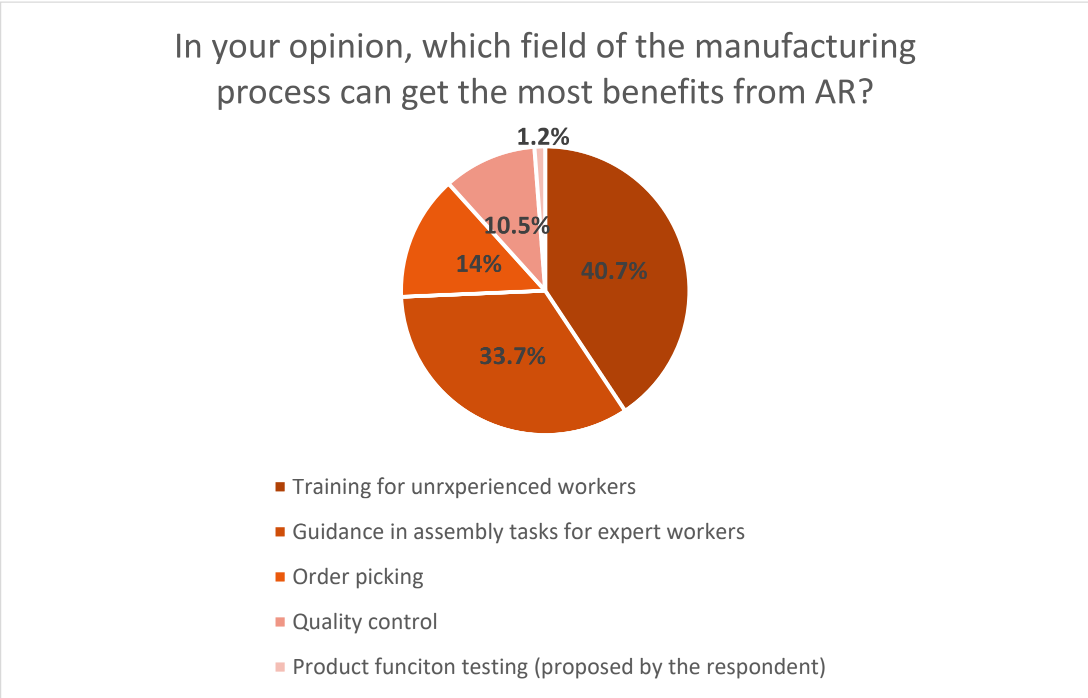

Figure 19. Survey: benefits of AR to manufacturing processes

In terms of areas where AR can contribute most of all, there was no common opinion among the respondents. Responses mentioned various manufacturing processes in the proportion presented in Figure 19. The area of training and guidance for expert workers should be paid extra attention to in the future because if future talents consider them as the most promising ones in terms of AR contribution, it also means that they will be more willing to use them there. It is good to start integration from the areas which are the most trusted, and then workers can see benefits and be more vulnerable to other changes.

Moreover, it is worth understanding to what extent students in general believe that AR systems will develop and integrate into manufacturing. As can be observed from Figure 20, the general trust in Augmented Reality as a beneficial tool in manufacturing is less than the readiness to work with it. Although most respondents evaluated their belief as 4 (45.3%), which is still a good result, there are a lot of hesitations if AR really will contribute to the manufacturing industry or not since there are a lot of people who graded their beliefs 2 and 3.

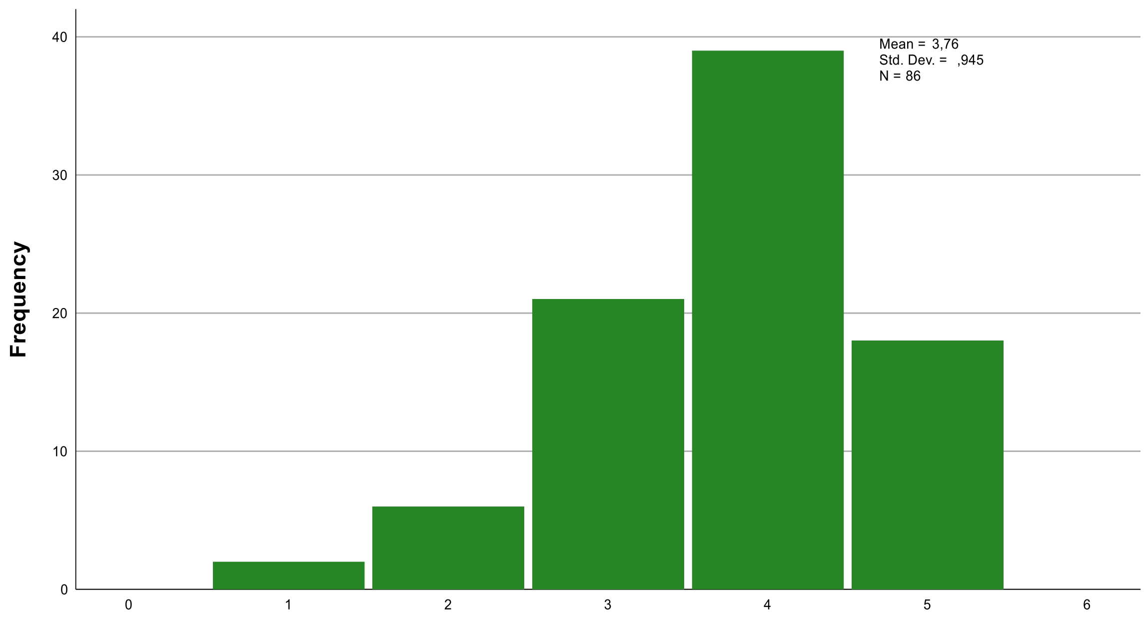

Figure 20. Histogram: trust in AR development in manufacturing

Although the assessment of trust level by students is rather low, the averages are not too downgraded and can be even regarded as high considering all the existing problems of AR and general people's unawareness of the technology. Since the standard deviation is rather high (0.945) because of the small data distribution and its higher concentration around evaluation number 4 (= mode), it is wiser to take the median as the main statistical parameter to assess the average level of students' trust in the AR development. In our case it turned out that 4,00 is an average extent of the young generation’s belief that AR technology will flourish and bring benefits to the manufacturing processes in the future (see Table 13).

Table 13. Statistical data on students' trust in the successful development of AR in the manufacturing industry

Statistics		
№	Valid	86
	Missing	0
Mean		3,76
Median		4,00
Mode		4
Std. Deviation		,945

Last but not least, it is of high priority to know which problems from the students’ point of view prevent AR from its successful integration into manufacturing. Although their opinion is not based on the real facts since respondents are highly likely to not have access to the inner companies’ information and concerns. However, it is curious to know what obstacles the future workforce has in mind and from what parties.

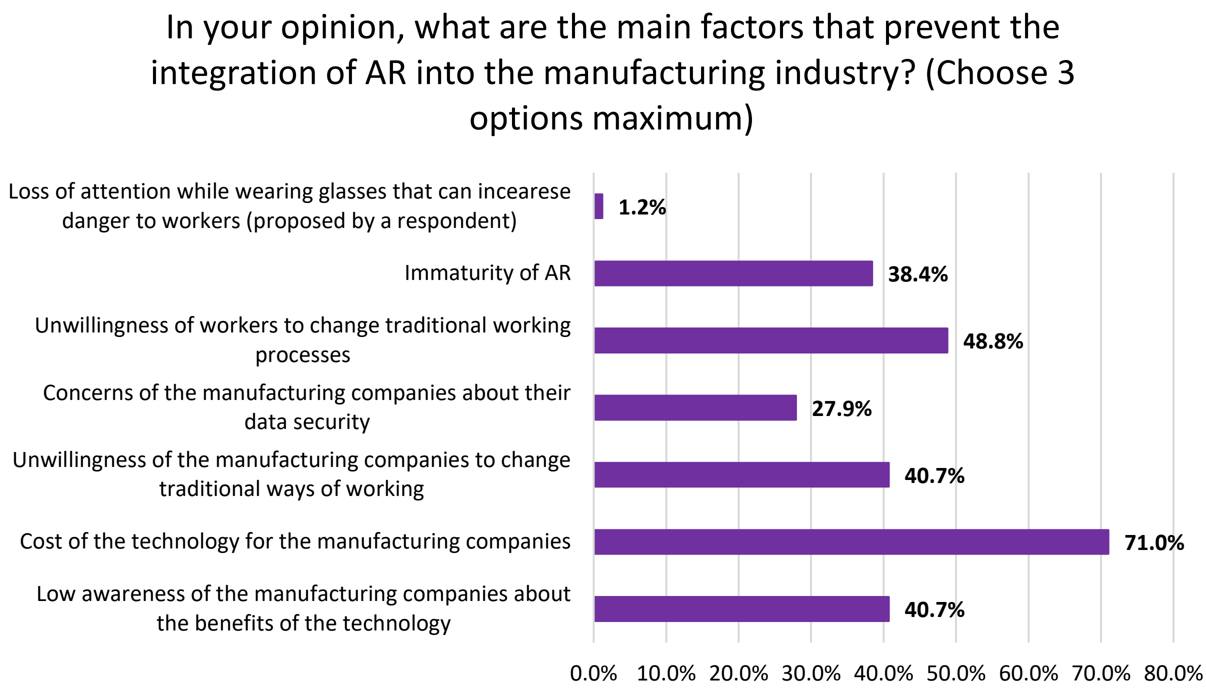

Figure 21. Survey: Challenges preventing integration of AR into the manufcaturing industry

The main reason that students claim to hinder the deployment of AR is the cost of the technology for manufacturing companies. They are convinced that hardware and software are expensive nowadays, and many companies cannot afford to buy and applying it in their processes.

It is surprising that future workers themselves mentioned the unwillingness of workers to utilize the technology because of a lot of changes in working processes as the second essential preventive reason (48.8%). Although other factors can be considered as more potential, not proved ones since it is based only on guesses of respondents, this aspect should be considered more seriously because it comes directly from those people who will use these devices in the future.

The same percentage (40.7%) stood for the reasons coming from the company's side: its unawareness of the benefits brought by AR systems and its unwillingness to change something in conventional ways of work. Students are sure that companies also do not understand completely how the technology works and what it can improve. Therefore, there is no demand and desire from their side to use it. Moreover, even some adolescents concluded that new technology would bring a lot of changes inside the organization, which can be seen as a preventive factor to investing and employ it.

Such aspects as the immaturity of the technology and possible problems with security also were mentioned as factors influencing the integration of Augmented Reality. Even a new issue was proposed by one respondent: s/he mentioned that a technology can be dangerous for workers since the display with augmented objects can be distracting and can lead to accidents in workplaces.

Extra comments

It would be remiss not to mention some comments given by students to the last open question asking to share any other concerns or ideas they have about AR. Two responses were found contributing to the research.

The first comment raises still a low level of trust in the technology and scare of being responsible for its actions. It is thought that if something goes wrong with the AR devices, the worker, not the technology, would be blamed for it. Thus, it is better for the worker just to rely on oneself than on the computer.

Comment 1: 'I would not trust such technology helping to fix a machine. Because the responsibility of fixing (and naturally doing something wrong) is on me, not on the machine. What if I do something wrong? Or the machine does not give the right directions etc. I definitely think in such a situation, a real competent and professional tech-support person can be trusted more, being a more reliable and effective problem solver.'

The second feedback concerns an idea not mentioned in this research yet. A student assumes that with the conventional way of manufacturing work, a company can micromanage its employees and consequently have control over them. If AR comes into action, it can take away this control since workers are able to become more autonomous with this technology.

Comment 2: 'Progress like this gives more autonomy to the employee and takes it away from the employer. Many big companies still want to micromanage their employees and this progress would take away control over the employee.'

By and large, the questionnaire brought a significant value to the research. It predominantly contributed to the third research question related to the perspectives of AR by highlighting ideas from the future talents about this technology, their trust in it, and possible obstacles in the way of its development.

4.3 Analysis of the author's observation

Although the author did not observe the work of AR glasses in manufacturing processes, it was still possible to make a few conclusions about the utilization of the technology in terms of some technical aspects and ergonomics.

Technically the virtual objects did not provide a very profound feeling of immersion. The way of controlling and managing AR objects by gestures and voice was not very comfortable because the technology did not always react or understand correctly what is asked.

Moreover, the ergonomics of the glasses was expected by the researcher to be better. Vizux felt more like normal glasses, but the FOV was so small that it was very hard to see everything needed without constantly turning one's head. They were also not well-fixed on the head, and it was supposed that they could easily fall in the working environment. HoloLens had a considerably bigger FOV, and it was easier to perceive the world. However, they were much heavier than Vizux. After 5-10 minutes of playing (not even working with them), it was already too heavy and not comfortable for the head and neck. And even after a such short time of working with the technology, headache appeared.

It was also noted that it is complicated to perceive a real and virtual world at the same time. Sometimes brain did not understand with which one a person should interact. It can bring possible danger to workers since a manufacturing environment is much more hazardous than just a simple room.

Thus, it was very useful to try the technology, but analyzing the whole work with the device, it turned out to be less developed than the author believed. It is still not so technological, ergonomic, and well thought-through. Although it is hoped that the next models of Vizux and HoloLens overcame significant enhancements, the author’s opinion about the current versions of AR glasses is that the technology is promising and can improve manufacturing processes, but there are still a lot of changes to be done before it can be completely acceptable for this purpose.

5 Discussion and Conclusions

In this final chapter, conclusions about the whole research are drawn. Firstly, research questions are answered, and the contributions of the work are described. Secondly, the author evaluates the research process and the quality of its findings. Finally, research limitations and implications for the further research are revealed.

5.1 Answering research questions

The main objective to screen potential pathways of how Industrial Augmented Reality can contribute to smart manufacturing in the future from its current state as practiced by manufacturing firms was achieved with the help of answering research questions.

RQ1: How is AR currently used in processes of smart manufacturing?

It was examined and found out that there are a lot of areas in manufacturing processes that can benefit from the AR utilization. The most prominent examples were mentioned and described in this work and their summary is presented in Figure 22.

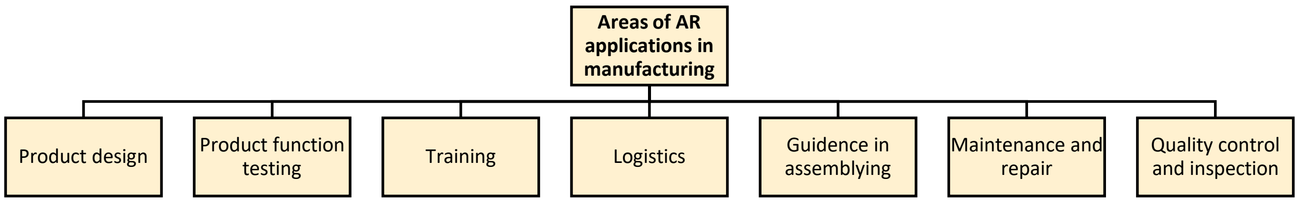

Figure 22. RQ 1: AR application in manufacturing processes

It can be observed that almost at each stage of product production a manufacturing company can gain advantages from using Augmented Reality systems. Moreover, there are already a lot of examples of the technology's real-life application in such companies as NASA, Boeing, Volkswagen, BMW, Airbus, Porsche, and many others. Although it is difficult to gain access to the inner information and understand the real value of the technology for the company, the start of its global integration should be already considered a promising sign.

However, in spite of the fact that there are notable number of use cases, the technology is still mostly at the stage of pilot projects. It is in general not so intensively used as it is presented, and its usage is mainly limited by big corporations because small and medium enterprises in most cases cannot afford this technology. The causes of AR still being on this stage and not being able to integrate massively are exposed in the research question two.

RQ 2: What are the current challenges that hinder the adoption of AR in smart manufacturing?

There is still a need for significant enhancements in the sphere of IAR. There are a lot of factors that hinder its successful integration into manufacturing companies. These challenges relate not only to the technology itself but also to the mindset of management and workers and the active participation of third parties.

The biggest part of the reasons was widely described in the literature review, then a few new notions were added during the primary data analysis. Hence, it was decided to sum up all the obtained information in a descriptive manner to have a whole picture of existing and potential issues of AR adoption in smart manufacturing.

Technical side

The first challenge relates to the hardware and software of AR. The technology on which a company's benefit depends on should be flawless in its execution. Nevertheless, it is still not the case. A lot of technical problems that need enhancements are reported, for example, tracking, authoring, or latency issues. The lack of standardized solutions also makes the technology more time- and money-consuming. Apart from it, the interaction of humans with the technology should in general be improved so that the latter one does not hazard the former one, and they work 'in cooperation'.

Continuing the theme of dangers to a human-being, ergonomics is another very important and consequently mentioned theme. AR headsets are not appropriate for work lasting longer than 2-3 hours, and even within this time there are some side effects noticed. First of all, the device is very heavy, and a worker is highly likely to have physical aches after its usage. Secondly, constant work in a small field of view and with appearing virtual images can be very complicated to manage. It can influence both the physical and mental health of workers and lead to such problems as dizziness, eye tiredness, headaches, etc.

Organizational side

The last category of challenges, and probably the most widely discussed and considered as one of the biggest reasons for integration hardships, is organizational changes. A lot of actors and facts should be taken into account: management, workers, and other third parties connected with AR development.

Another problem is a lack of knowledge inside the companies of the technology, its functioning, and its benefits. A difficulty for AR to integrate into manufacturing organizations can be explained by the fact that they do not know the technology and what it can bring to them. Neither management, nor workers are aware of it, and the problem is that it is still unclear who should bring this knowledge to them and how: if it should be educational institutions, companies providing AR services, governments, or someone else.

Besides, sometimes there is the unwillingness of both management and workers to change conventional processes by introducing a new technology, changing all systems, way of work, organizational structure, and a lot of other alterations. From the management side, it also adds extra concerns in terms of money (investment risk) and time (personnel training, seeing the benefits). For the employees it is in general stressful and asks for a lot of effort to accept and trust the machine.

Finally, AR raises a lot of security-related concerns. Companies need to give access to their manufacturing information to a third party (AR-providers) to integrate devices into the inside industrial processes. Workers also worry about it since they can feel ‘surveilled’ while working. However, it is the problem connected with all electronic devices inside the company that have access to the company’s private data. It means that technology should have a very high level of security without any flaws which in terms of AR is still very time-consuming and expensive to do.

RQ 3: What are the future perspectives of AR development in the manufacturing industry as seen by current AI and manufacturing experts in comparison to the future talents?

Considering the state of AR utilization in manufacturing companies, the existing challenges for its further successful development, opinions of experts and the future workforce, the third research question about future perspectives of AR deployment in the manufacturing industry can be answered.

On the one hand, it is thought by the present-day experts that in a period from 3 to 10 years AR technology will improve to an extent so that it can be massively integrated into manufacturing processes and bring the maximum benefits. For this forecast to come true several requirements should be met. Firstly, all mentioned challenges that AR has nowadays should be solved or at least their state should be considerably improved so that there are no big doubts and dangers for using it. Without solving problems and trying to add something else or push companies to use the technology, there will be no success since it will just lead to its failure and rejection. Secondly, some combinations with other technologies that can increase the efficiency of AR should be found. Even some parts, processes, or the way of functioning of other inventions that can bring benefit can be added to AR systems. For instance, 5G for Industry can enhance the online communication part of AR technology. Another example of technology combination that is very promising is AR with Digital Twins. Influencing each other mutually, they can affect each other's development and integration into manufacturing considerably.

On the other hand, the future talents are still doubtful about the way of AR further development in manufacturing industry. A lack of homogenous opinion about the future of the technology can be explained by different reasons, one of which is unequal distribution of knowledge about AR among current students. Therefore, addressing this issue as well as paying special attention to the opinions and readiness of future workforce is of high importance because if they are not ready to accept the technology, work with it, and/or do not have trust in its usefulness, it will be very complicated to integrate AR devices without workers' desire. It is essential to increase the consciousness of students of AR and other technologies as well already now. The more one knows something and the more one understands how it functions, the more trust there will be because all positive and negative impacts will be known.

5.2 Theoretical and practical implications

Conducted research contributes both theoretically and practically to the studied issue.

As for the theoretical implications, some already existing knowledge regarding AR is firstly summarized in the literature review. It is considered an important contribution because the author found that some works on this topic lacked comprehensiveness and an overview of the problem from different sides. There are some good researches in this area, but they are more specified on one or a few aspects. It is beneficial to take information from these profound researches and combine it in one taking past, present, and future of the technology into account, as it was done in the current research, to understand the whole situation.

Secondly, the opinions of experts who deal with this technology nowadays contributed to the theoretical knowledge. The technology does not stop in its progress, and even some notions and facts from 2 years ago can be already not valid. Opinions about the state of the technology nowadays including its current application in companies and challenges, as well as predictions and viewpoints about its future were discovered and analyzed.

The last theoretical implication relates to the future workforce's view of the technology, in particular, their trust in it, readiness to work, ideas about its usefulness, problems, and future in general. Theory needs to consider this data as well since it can give an understanding in which directions it is better to improve and what to expect from people who will take control of manufacturing firms in the future.

There are two main practical implications. This research shows to AR-producing companies which drawbacks the technology has. It creates a practical future development path for them to follow and reveals what particular aspects they need to improve in the following years.

Another conclusion that should be taken from this research and put into action is the urgent need of increasing companies' and the younger generation's awareness of AR. Educational institutions should teach students about its functioning and possibilities so that they are more open to the technology and can in the future bring this knowledge to companies. Besides, companies that produce and distribute AR technology should bring consciousness to the companies about AR systems. Enabling understanding, providing examples, and explaining real-life solutions and benefits, they can accelerate acceptance of the technology and its integration into manufacturing processes. Apart from it, if the government aims to make advancements and enable progress in the manufacturing industry, they should provide more support to the technologies that can do it, including AR as well.

5.3 Assessment of research process and results quality

The research followed the initial implementation plan and chosen research methods described in Chapter 3 (Methodology and Implementation). The whole process took about 10 months. Data was collected and presented in a clear structured way. A plan for the research quality and ethics was also complied with.

The results of the research must be both reliable, implying that they will produce the same results if repeated, and valid, meaning that they measure what they are supposed to (Saunders et al., 2012). There are a lot of factors that can influence it and that are very hard to be spotted and controlled. However, the researcher should try to do the maximum so that the result of the work meets standards and requirements.

As for the reliability of results, it is believed that responses and findings would remain the same with interviews and survey are conducted again. Validity is also considered to be at a high level since it is thought that respondents and researcher did their maximum to provide valid results and exclude as much as it is possible the influence of biases.

Interviews were all conducted either in the morning or afternoon in the suggested, thus comfortable for the expert, time. All biases mentioned in subchapter 3.3.2 (Primary data) were considered and tried to be avoided. Questions followed each other logically and allowed us to understand an expert opinion because they were focused on the theme and did not go out of the field of the researcher's interest. Besides, there were no questions that can touch or offend one's personal life, opinions, or beliefs. The experts were also not pushed to answer any questions if they do not want or do not possess the knowledge needed for a proper answer. A needed time to think about responses was always provided. Information about the usage of gained data was given.

The questionnaire was built according to rules and with avoidance of possibly emerging biases (subchapter 3.3.2). It was re-edited several times and tested before reaching the respondents. No one was forced to answer the survey. The links were sent in the afternoon on a working day in March which is important because it was not the time when students go on vacation. Thus, there was no hurry with answers: respondents could take their time, and the researcher could wait patiently for enough answers. The purpose of the survey and the way how it will be used were also mentioned there. Questions that checked the attentiveness of the respondents were also included. There were some connected questions but asked in different manners. Consequently, answers which did not have sense in these 'checking points' can be considered not credible enough. The questions were clear and should have been understood by all respondents.

Another factor that is worthwhile mentioning is that a researcher tried to stay objective while analyzing the data and present it in a neutral way. The author also does not represent any organization or company, thereby all mentioned companies or dis/advantages of the technology come from the analysis of primary and secondary data. The personal observation of the author with AR added credibility to findings since there was a possibility to check in real life if mentioned challenges and opinions about the device genuinely exist and correspond with reality.

Even though the results are regarded as reliable and valid, some factors could influence these aspects of the research. The sample of the research was not big and heterogeneous to make global generalizations and conclusions about the topic. That is why generalizations and some conclusions in this research should be more seen as proposals and aspects that should be paid extra attention to and studied more carefully.

5.4 Research limitations

There are some factors that limited research. The first one was already partially mentioned in the previous section: it concerns the small size and homogeneity of the interview and survey respondents due to the lack of the student's connections and sources. 6 interviewees and 86 survey respondents cannot represent the whole picture and reflect the global situation. Furthermore, experts were originally only from two countries (Finland and Russia), thus they can mostly observe the subject in terms of their country/company and more superficially regarding others. The geographical situation was better among respondents since the difference in countries varied a lot. Nevertheless, 1-2 people from some countries cannot truly show the opinion of everyone.

Another important fact that should be mentioned about interviewees specifically, it lacked a manager or worker in the manufacturing industry. Both those who already use this technology, and those who do not apply it or even do not know anything about it would be useful. It is valuable and important to gain information and opinions from inside the company because it is them at the end who will use the technology, but it is complicated to make a company share some data from inside. Therefore, it is hard to find out from the companies who already use AR what truly the benefits are or how ready those who do not utilize it yet to start its integration.

In addition to it, such aspects as time constraints and narrowing down the research theme in the frame of a bachelor thesis limited the researcher and influenced chosen methodologies and consequently the content of the work.

5.5 Implications for further research

Augmented Reality has already started its path of development and integration, however, there are still issues to be solved. This research covered a considerable part of AR's current state, problems, and future and comprised opinions of different people on this technology. However, there is yet work to do and issues to be studied. Some implications for future research are proposed in this section.

1. The more considerable amount of people for interviews, especially from inside the manufacturing and AR producing companies, and surveys can be found and questioned. Such research in terms of the same theme will provide a wider, global, and more credible overview of the problem and will highly likely bring up new problems or solutions.

2. Research regarding the solution to existing AR challenges can also be done from the technological and psychological sides. The former one will address at more profound level problems connected with the hardware and software of the technology and propose possible solutions. The psychological side can scrutinize the problem of people's awareness of the technology and its acceptance and try to solve this urgent issue.

3. Another suggestion for a research topic can be AR in combination with other technologies. For example, it was mentioned that AR and DT are a very promising mix. It is also possible to research which impact 5G for Industry can have on Augmented Reality. Both of these topics can be studied more deeply and bring an understanding in which ways these technologies can influence each other, where and how to use them and what potential problems can appear.

4. The last future research implication is AR and Industry 5.0. There are already discussions about Industry 5.0 that will concern European industry and focus on its sustainability, human safety, and resilience. It can be studied how Augmented Reality can contribute to this new industrial era and its purposes.

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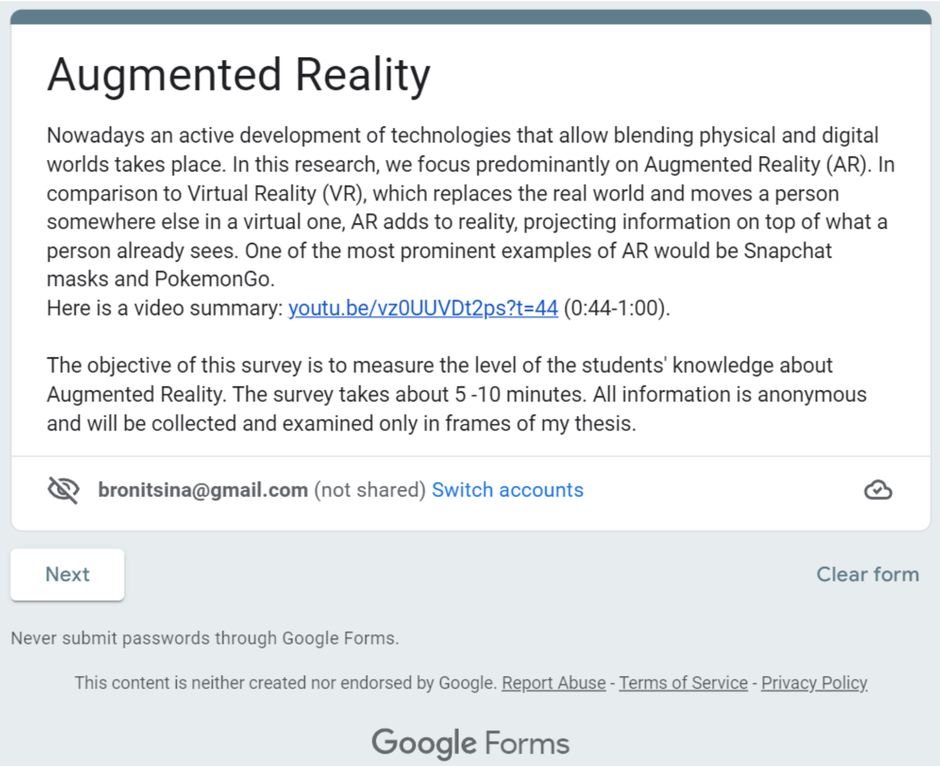
Appendices

Appendix 1. Interview Sample Questions

1. Could you, please, tell me about your professional background and current work?
2. Could you, please, specify, in what ways or for what purposes you use or relate to AR at work? What is your opinion/point of view on AR based on this experience?
3. How mature do you think the current AR is?
4. Are you familiar with the concept of smart manufacturing? What does it mean to you personally?
5. What are the main areas/stages of the manufacturing processes, in your opinion, which can benefit from the application of AR? Specify its positive impact.
6. Do you know how and where AR is currently of use in manufacturing processes?
7. What are, in your opinion, the current challenges that hinder the adoption of AR in smart manufacturing? Where in the "value nets" are the challenges? What are the missing resources?
8. What are the most significant changes that should be done to accelerate the process of AR integration? And in which level/organizations the improvements should be made?
9. What are, to your mind, the future perspectives of AR development and its deployment in the companies of manufacturing industry?
10. Can you imagine and describe a positive scenario or a negative scenario of AR input into smart manufacturing?
11. Is there anything else you want to add, or you think I should know about this topic?

Appendix 2. Survey



Augmented Reality

Nowadays an active development of technologies that allow blending physical and digital worlds takes place. In this research, we focus predominantly on Augmented Reality (AR). In comparison to Virtual Reality (VR), which replaces the real world and moves a person somewhere else in a virtual one, AR adds to reality, projecting information on top of what a person already sees. One of the most prominent examples of AR would be Snapchat masks and PokemonGo.
Here is a video summary: youtu.be/vz0UUVDt2ps?t=44 (0:44-1:00).

The objective of this survey is to measure the level of the students' knowledge about Augmented Reality. The survey takes about 5 -10 minutes. All information is anonymous and will be collected and examined only in frames of my thesis.

bronitsina@gmail.com (not shared) Switch accounts

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Augmented Reality

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*Required

What is your study field? (Try to choose the closest one and use 'others' only in case you cannot connect your degree with any of the below-mentioned options) *

- ◯ Agriculture
- ◯ Arts
- ◯ Business, administration and law
- ◯ Education
- ◯ Engineering, manufacturing and construction
- ◯ Health and welfare
- ◯ IT
- ◯ Social sciences
- ◯ Other: ________

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Prefer not to say
- ◯ Other: ________

What is your age?

- ◯ <18
- ◯ 18-25
- ◯ 26-35
- ◯ 36-45
- ◯ >45
- ◯ Prefer not to say

Country *

Choose ▾

Have you ever heard about 'Augmented Reality' (AR) before? *

- Yes
- No
- Not sure

Do you think you have already used Augmented Reality in your life? *

- Yes
- No
- Not sure

Has AR ever been the subject or a part of a course you have taken? *

- Yes
- No
- Not sure

Back Next Clear form

Augmented Reality

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*Required

AR Application in Smart Manufacturing

This survey focuses on AR development and application in manufacturing. AR devices and applications can provide instructions, support, location of needed details, and much more. They can bring benefits to both workers themselves and companies. However, this technology is only starting to 'gain momentum' and still has a lot of challenges to overcome.

Have you ever had a personal interest in the topic of AR application in manufacturing? *

- Yes
- No

Have you heard about any company that uses AR technology in its manufacturing processes? *

- Yes
- No

If yes, please, specify which ones.

Your answer

Imagine that you started to work in a corporation that produces automobiles. All new workers of the assembly line should complete one week of training. Instead of being taught by a person, they are provided with a headset of AR glasses which show instructions about the assembly process. Would you be ready to use such AR glasses for your training? *

	1	2	3	4	5	
Definitely would not	○	○	○	○	○	Definitely would

In your opinion, what are the features of the headset that in this case would be the most important? (Choose maximum 3 options) *

- ☐ Ergonomics
- ☐ Graphics
- ☐ User-friendliness
- ☐ Speed of processing
- ☐ Battery autonomy
- ☐ Privacy and security of information given and stored
- ☐ Feeling of immersion and collaboration
- ☐ Other: ____________

Imagine you are working in the same company for a year, and there is a breakage of the machine. You have never faced this problem before, and you do not know how to fix it. Luckily, you have AR glasses that can connect you with an expert who will guide you step by step (i.e pointing at objects, drawing, and showing pictures/videos via glasses). Would you be ready to use AR glasses in such a situation? *

	1	2	3	4	5	
Definitely would not	○	○	○	○	○	Definitely would

In your opinion, what are the features of the headset that in this case would be the most important? (Choose maximum 3 options) *

- ☐ Ergonomics
- ☐ Graphics
- ☐ User-friendliness
- ☐ Speed of processing
- ☐ Battery autonomy
- ☐ Privacy and security of information given and stored
- ☐ Feeling of immersion and collaboration
- ☐ Other: ____________

In your opinion, which field of the manufacturing process can get the most benefits from AR? *

- ◯ Training for unexperienced workers
- ◯ Guidance in assembly tasks for expert workers
- ◯ Order picking (help in finding correct details in a warehouse)
- ◯ Quality control
- ◯ Other: ______

To what extent do you believe in the development of AR in manufacturing processes? *

	1	2	3	4	5	
Very low	◯	◯	◯	◯	◯	Very high

In your opinion, what are the main factors that prevent the integration of AR into the manufacturing industry? (Choose 3 options maximum) *

- ☐ Low awareness of the manufacturing companies about the benefits of the technology
- ☐ Cost of the technology for the manufacturing companies
- ☐ Unwillingness of the manufacturing companies to change traditional ways of working
- ☐ Concerns of the manufacturing companies about their data security
- ☐ Unwillingness of workers to change traditional working processes
- ☐ Immaturity of AR
- ☐ Other: ______

Are there any other issues related to AR that you would like to raise?

Your answer ______

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