The State of Augmented Reality, Mixed Reality and Virtual Reality adoption and use in European small and medium-sized manufacturing companies in 2020

VAM Realities Survey Report

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List of abbreviations and definitions

3D: Three-dimensional.

AEC: Architecture, Engineering, and Construction.

API: Application Programming Interface: a computing interface for defining interactions between different software and information systems.

AR: Augmented Reality: a technology that adds digital content into the user's view of the real environment via various devices such as smartphones, tablets, and head-mounted displays.

B2B: Business-to-Business.

BIM: Building Information Modelling: a 3D-model based process for creating and managing intelligent digital and functional representations of physical buildings.

CAD: Computer-Aided Design: software that is used in creating digital designs of various products and entities.

HEI: Higher-Education Institution.

HMD: Head-Mounted Display, head-worn devices used in creating AR, MR and VR experiences.

IoT: Internet of Things, a network of devices embedded with various sensors, software, and other technologies, IoT devices connect and exchange data with other devices and systems over the Internet.

MR: Mixed Reality, a technology that merges real and virtual worlds to produce new environments and visualizations, where physical and digital objects co-exist and interact in real time. Often viewed as a more advanced version of AR where the digital content interacts with the real environment more extensively.

ROI: Return on Investment.

SME: Small and Medium-sized Enterprise.

VR: Virtual Reality, a technology for creating an immersive and interactive three-dimensional computer-generated environment in which the virtual objects have spatial presence. HMDs are often used in creating the VR experiences.

XR: Extended Reality, an umbrella term for AR, MR and VR.

Executive Summary

This report provides an overview on Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) adoption and use in European manufacturing SMEs in 2020. AR is a technology that combines digital objects into the user's view of the real world with various devices, such as smartphones and head-mounted-displays (HMDs). MR is often used to refer to more advanced AR solutions, although they are also often used interchangeably. VR on the other hand replaces the user's view of the real environment with a simulated virtual world with the help of VR HMDs. The AR, MR, and VR markets, which together constitute the overall Extended Reality (XR) market, are expected to grow rapidly during the next few years. These technologies became relevant for organizations with the emergence of the new wave of AR and VR hardware in 2016, namely with the commercial release of the Oculus Rift and HTC Vive VR glasses, and the unveiling of the Microsoft HoloLens AR glasses. However, despite the initial excitement provided by these novel technologies, it soon became obvious that the necessary enterprise software and information systems did not yet support these new devices sufficiently to enable efficient and rapid workflows in organizational business processes. For example, digital building information models (BIM) used in the construction industry often took hours or days to export into AR or VR. This process also required manual optimizations and using several different software in order to create usable visual models for AR/VR use. This made using AR/VR time-consuming, costly, and impractical.

However, now that AR and VR software have had a few years to catch up, many AR and VR software have been able to develop efficient pipelines between various software and organizational information systems and AR/VR solutions. For example, exporting digital models (such as BIM) into VR can now be done in seconds or minutes by the click of a button. Moreover, it is now even possible to edit CAD models in real-time inside VR, which can enable novel business processes. The release of vastly improved hardware chipsets (such as the Snapdragon XR2) used in the newest AR/VR devices are now also further expanding the possibilities for future software innovations in the AR/VR space, as well as business opportunities for manufacturing SMEs.

These developments have made it increasingly possible to adopt these technologies in companies to increase the efficiency of organizational business processes. Accordingly, companies should take a renewed look at how different XR solutions could be implemented in their companies. In addition, the COVID-19 pandemic has also forced many companies to start working remotely which has compelled companies to try to find more effective ways of carrying out their business processes remotely to adapt to this new reality. This situation has accelerated the already existing trend of increasing remote work. AR and VR both present intriguing opportunities for making remote work more engaging, effective, and efficient. For example, reviewing 3D models of new product designs can now be done collaboratively in VR whereas AR can make remote support more intuitive for employees. These types of solutions can help employees stay connected even though they might not physically see each other for extended periods of time.

However, small and medium-sized enterprises (SMEs) need to take into account many different factors and requirements if they wish to start using XR technologies in their organizations. The VAM Realities project (co-funded by the Erasmus+ Programme of the European Union) set out to explore these issues at the beginning of 2020. We carried out 46 interviews in nine European countries and collected data from 255 respondents on the use of AR and VR in organizational settings with a survey. This document reports on these findings and results.

The majority of the surveyed companies were still not using AR or VR (around 60 %), but a sizable minority (around 25 %) were using them sometimes with a smaller group (around 15 %) using them very often. However,

the majority of respondents were aware of the potential that these technologies have in their organizational context but had not actively planned on using AR or VR yet. Nevertheless, a majority of the respondents (65 %) also thought that their company would use AR or VR in the future. Several different adoption barriers were identified in the interviews and via the survey.

An innovative organizational culture and support from the top management were found to be necessary for AR/VR adoption. Managers should therefore acquire at least a basic understanding about these technologies, where they can be used, and what limitations they might have in their enterprise context. Employees should also be given time to delve into these technologies to figure out how they could be best used to support or transform their businesses. However, in companies which do not have employees who could be characterized as digital innovators, it is likely that AR/VR solutions will need to be acquired as complete turn-key packages in cooperation with external vendors.

Companies will also need to identify the best opportunities for testing AR/VR hardware and software. University cooperation, industry associations, and vendor demonstrations were identified to have the most potential in this regard. Due to the novel nature of XR technologies, first-hand experience with relevant use cases was found to be essential for understanding their potential and limitations. These testing situations should be made to be as engaging and practical as possible in order to mitigate any possible apprehension from the employees towards XR.

It is also important for companies to evaluate how well their current software and information systems can be integrated with the currently available solutions because the value of AR and VR comes mainly from presenting existing digital information to users in novel and efficient ways. In this regard, streamlined AR and VR functionalities and plugins have become available for many design software (e.g. in the BIM and CAD context) just in the last few years (2019-2020). Companies should therefore examine whether these new tools could be more easily adopted than in previous years when the first new AR and VR devices became available.

Most of the surveyed companies reported that their competitors were still not using AR or VR in a noticeable way to the best of their knowledge. However, due to the COVID-19 pandemic and ever-increasing remote work, exploring how AR and VR can create a competitive advantage in this new situation can be advantageous for companies. In the short-term, AR and VR adoption and use will still most likely focus on internal business processes or facilitated customer-facing activities because customers still largely do not have the necessary AR or VR equipment in use. Acquiring competences with AR and VR will also increase the possibilities for expanding AR and VR use in the future as more powerful solutions become available. Higher-education institutions (HEIs) can also provide important support to SMEs in acquiring these skills and capabilities through consultancy and research project collaboration.

This report was finalized in January 2021.

1 Background and objectives

Augmented Reality (AR) and Virtual Reality (VR) are both expected to have a major effect on organizations in the coming decades. Several different **forecasters are predicting that the AR and VR markets will grow significantly in the coming years.** For example, Digi-Capital is predicting that the AR and VR markets will grow to $65 billion by 2024[1]. Organizations need to therefore be aware of these technologies, where they can be used, and what factors can promote their effective adoption in their organizations. In order to address this topic, the Erasmus+ co-funded VAM Realities project was launched at the beginning of 2020 to help European SMEs better understand these issues. This report is one of the first outputs of the project and it aims to address how aware SMEs are about AR and VR technologies, how they are currently used, and which organizational, technological and external issues affect their adoption in the SME context.

Both AR and VR have been in development for decades. In the 1990s, VR experienced a lot of hype as the first consumer-grade VR headsets became available. However, it soon became obvious that the technology simply was not ready for primetime at that time and VR was then largely relegated back into university research settings for almost two decades. However, **the release of the Oculus Rift in 2016 (as well as the HTC Vive) along with other advances in VR hardware, information processing, software, and wireless communication have now truly made VR use feasible in organizational settings.**

Figure 1. Examining a manufacturing design in VR (Photo credit: Eddie Kopp/Unsplash)

As more and more smartphones and tablets have also started supporting AR, its potential in the enterprise setting has also increased in the recent years. The massive popularity of the Pokémon Go AR app further points

[1] https://www.digi-capital.com/news/2020/04/how-covid-19-change-ar-vr-future/

to the inherent potential of this techn. Moreover, **dedicated AR headsets such as Microsoft's HoloLens have also advanced AR technology further at an increased pace.** These types of advanced AR solutions where the digital content interacts with the environment more accurately are also often referred to as Mixed Reality (MR). However, MR is also often used interchangeably with AR. Collectively, these technologies (AR, MR and VR) have been recently referred to as Extended Reality (XR) (for more in-depth examination of these technologies, please read section 3.2. on page 13).

Figure 2. AR content viewed through a tablet (Photo credit: Patrick Schneider/Unsplash)

Besides the technical developments with XR technologies, significant external factors, namely the COVID-19 pandemic, have now spurred further interest into using XR in organizations. Moreover, **some researchers[2] are now predicting that the lack of physical meetings might lower productivity and innovation in organizations for years to come.** As the pandemic has now forced many companies to go almost fully digital and carry out most of their activities remotely, companies have also scrambled to find the most effective tools to help them navigate this unprecedented situation. AR and VR provide interesting opportunities in performing organizational business processes remotely. As the COVID-19 pandemic has further increased the prevalence of remote work, **it is important for companies to re-evaluate their activities and figure out whether some activities could be performed more efficiently and effectively with the aid of novel technologies, such as AR and VR.**

Despite the hype around XR, many companies are still not sufficiently aware of the potential of these technologies and how they could be used to support their business processes, or what challenges they might face when adopting them. Consequently, the VAM Realities project set out to examine what companies currently know about AR, MR and VR, where they are used, and what factors affect their adoption in the

[2] Gorlic, A. (2020). The productivity pitfalls of working from home at the age of COVID-19. https://news.stanford.edu/2020/03/30/productivity-pitfalls-working-home-age-covid-19/

manufacturing and industrial SME context. In order to study these issues, the project interviewed numerous manufacturing and industry SMEs and collected feedback from companies on these issues with a quantitative survey.

The purpose of this publication is to report on these survey results and interview findings to provide insights on AR/MR/VR adoption and use by European manufacturing SMEs. However, this report mainly focuses on the use of AR and VR as they are more familiar to companies when compared to MR. In this survey report, we describe the results of a quantitative survey with 255 anonymous respondents as well as 46 interviews with SME companies. Managers and experts from SMEs as well as some larger companies from Germany, Austria, Cyprus, Spain, Italy, Belgium, the Netherlands, Estonia, and Finland participated in these interviews or filled out the survey. The findings from the interviews form up the core of the report with quantitative data from the survey being mixed in at relevant parts.

Next, we will describe the methodology of the interviews and the survey in more detail. Following this, the findings and results of the report are presented. The findings of the survey report are organized under five main sections:

(1) Awareness and preferences of SMEs regarding AR, MR and VR
(2) Critical use cases for AR and VR in industry
(3) Organizational factors affecting the adoption and use of AR, MR and VR in SMEs
(4) Technological factors affecting the adoption and use of AR, MR and VR in SMEs, and
(5) External factors affecting the adoption and use of AR, MR and VR in SMEs

Finally, we present the conclusions of the report and give out recommendations and a 10-point action plan for European SMEs on how they can best adopt and use AR/MR/VR technologies to support their businesses as well as how the VAM Realities project can support SMEs in these activities.

2 Methodology - data collection and data analysis

The aim of this survey report is to provide insights for the managers and other employees of industrial and manufacturing SMEs on the use and adoption of AR, MR and VR. In order to achieve this, the VAM Realities project carried out 46 interviews with European SMEs and collected 255 anonymous responses from industrial and manufacturing SME managers and experts with an online survey.

2.1 Data collection

The VAM Realities AR/VR survey and interviews were carried out between April 2020 and October 2020. The semi-structured interview guide and the survey were developed by Tampere University (Finnish project partner of the VAM Realities project) and revised based on feedback from other VAM Realities project partners. The interview guide had four overall themes that were explored in the interviews: (1) Awareness and use of AR/MR/VR as well as (2) organizational, (3) technological and (4) external issues affecting adoption and use of these technologies. The duration of these interviews was between 45 and 75 minutes and they were mainly carried out via video meeting tools (such as Zoom and Microsoft Teams) due to the COVID-19 pandemic. The interviews were recorded with the consent of the interviewees. The project partners from Austria (ENTER Network), Belgium (KU Leuven), Cyprus (CARDET), Finland (Tampere University), Estonia (Tallinn University of

Technology), Germany (FHM), Italy (STIIMA-CNR), the Netherlands (Parbleu), and Spain (FVEM) interviewed five SMEs each and created an interview summary from each of the interviews for later analysis. The interview summaries also included several transcribed quotes. The project partners interviewed lower, middle, and top-level managers as well as some expert-level employees from manufacturing and industrial SME companies although a few larger companies were also interviewed to provide contrast to the findings.

The online survey was developed based on existing scientific literature by adapting statements from various scientific journal articles to fit the context of the present survey. The respondents were asked to answer the survey statements by choosing a response from a 7-point Likert scale ranging from 'Strongly disagree' to 'Strongly agree'. The survey was pilot tested with two SMEs from Finland and Italy and revised based on this feedback. The survey was also translated into German, Italian, and Spanish. Each partner distributed the quantitative online survey in their respective networks to potential respondents from the manufacturing and industrial SME sector. The respondents were kept anonymous. The aim of each partner was to collect 25 responses to the survey. The survey included both open-ended and closed questions and it was broken into two parts. Firstly, the questionnaire collected background information on the respondents and the overall status of AR and VR use in their companies. 255 respondents answered to this shorter part of the survey. Next, the survey asked the respondent to choose which of these technologies had the most potential for their companies. This was followed by 49 questions on different factors that could affect the adoption of the chosen technology. 213 respondents also answered this final part of the survey in full. A selected assortment of these results is also included in this report. The survey data will also be examined and analyzed in upcoming scientific publications.

2.2 Data analysis

Each partner sent its interview summary documents to the Finnish partner (Tampere University) for analysis. Tampere University was primarily responsible for writing the final survey report. The aim of the analysis was to identify how aware the SMEs were of the potential of AR, MR and VR in their enterprise context, how they were used in their companies at the moment or how they might be used in the future, and what barriers they felt were the most critical in any future use of these technologies. The analysis began with the interview results which formed the core of the report. The results from the survey were then added to the report to complement the qualitative analysis.

The initial draft of the survey report was first reviewed internally by each partner and it was then modified based on their recommendations. Afterwards, the survey report was then sent to be reviewed by the external Associated Partners of the project. This feedback was then taken into account and the report was revised accordingly. Finally, the report was proof-read by a native English speaker before it was published.

2.3 Background information about the survey respondents

The following Tables 1, 2 and 3 provide information about the survey respondents and the companies they represent. As can be seen from Table 1, a significant majority of the respondents were male (80 %) and the respondents were pretty evenly distributed age-wise. As can also be seen from Table 1, the vast majority of the respondents (82,7 %) held an advanced degree or a bachelor's degree (58,4 % and 24,3 %, respectively). The respondents were evenly distributed between lower (23,9 %), middle (31 %), and top management (30,2 %) with 14,9 % of the respondents choosing 'Other' (indicating they were experts or other employees).

Table 1. Gender, age, education level, and organizational position of the survey respondents.

Gender		
Male	80%	204
Female	20%	51
Age		
18 to 24	3,1%	8
25 to 34	29,0%	74
35 to 44	23,9%	61
45 to 54	27,1%	69
55 to 64	15,3%	39
65 to 74	1,6%	4
Education		
Graduated high school	4,3%	11
Trade/technical school	5,1%	13
Some college, no degree	3,5%	9
Associate degree	3,1%	8
Bachelor's degree	24,3%	62
Advanced degree (Master's, Ph.D., M.D.)	58,4%	149
Organizational position		
Lower level management (e.g., Project manager)	23,9%	61
Middle management (e.g., Department manager)	31,0%	79
Top management (e.g., Chief Technology Officer)	30,2%	77
Other	14,9%	38

As can be seen in Table 2, most of the companies operated globally or at least nationally (56,5 % and 29,4 %, respectively). Most of the responses were from the native countries of the project partners with a few additional responses from other European and non-European countries. The survey results are therefore not significantly skewed by answers from any specific country.

Table 2. Country and operating area of the surveyed companies

Operating area		
Locally	14,1%	36
Locally and nationally	29,4%	75
Locally, nationally, and globally	56,5%	144
Location		
Austria	10,6%	27
Belgium	10,2%	26
Cyprus	13,7%	35
Estonia	5,1%	13
Finland	12,9%	33
Germany	9,4%	24
Greece	0,8%	2
Ireland	0,4%	1
Italy	8,2%	21
Netherlands	11,4%	29
Romania	0,4%	1
Spain	16,1%	41
Outside of Europe	0,8%	2

As can be seen in Table 3, the respondents' companies mainly had other businesses as their customers (i.e. B2B companies constituted 60,4% of the respondents) followed by consumers (16,1%), and public organizations (6,3%). The respondents represented various industries with architecture and construction (15,3 %), machinery and equipment (11,4 %), metals (8,6 %), computers and electronics (7,8 %), industrial installation and maintenance (7,1 %), and automotive and vehicles (6,7%) comprising the biggest segments. The largest single answer category was 'Other' (23,1%) where the self-reported industries included sectors such as education and consulting. No industry was therefore predominant in the survey responses. A vast majority of the responses

(76,9 %) were from SMEs (under 250 employees) because SMEs were the primary focus of the VAM Realities project.

Table 3. Size, industry, and primary customers of the surveyed companies

Employees		
1-9	19,2%	49
10-49	32,2%	82
50-250	25,5%	65
251-500	6,3%	16
501-1000	2,7%	7
> 1000	14,1%	36
Industry		
Aerospace	2,4%	6
Architecture and construction	15,3%	39
Automotives and vehicles	6,7%	17
Biotechnology	0,4%	1
Chemicals	1,6%	4
Clothes and textiles	0,4%	1
Computers and electronics	7,8%	20
Electrical equipment	3,9%	10
Food and beverages	3,5%	9
Furniture	1,2%	3
Healthcare and pharmaceuticals	5,5%	14
Industrial installation and maintenance	7,1%	18
Machinery and equipment	11,4%	29
Metals	8,6%	22
Plastics	1,2%	3
Other (e.g. Education, Consulting etc.)	23,1%	59

Primary customers		
Businesses and companies	60,4%	154
Consumers	16,1%	41
Distributors/agents/dealers	4,7%	12
Governmental institutions	2,4%	6
Higher education or research institutes	3,9%	10
Public organizations (e.g., schools, hospitals)	6,3%	16
Other, please specify	6,3%	16

Next, we will go over the findings and results from the survey and interviews. First, we will start with the level of awareness that manufacturing SMEs have about AR/MR/VR and their level of use.

3 Current state of AR, MR and VR in European manufacturing SMEs

3.1 SMEs' awareness, current use, and perceived limitations regarding AR, MR and VR

Over the last few years, AR and VR have become increasingly prevalent in the personal entertainment context. Many of the interviewees also noted that they were still more familiar with AR and VR in the gaming context rather than in their professional work. This is not that surprising when taking into account the popularity of gaming titles such as Pokémon Go for AR (released in 2016) and Beat Saber for VR (released in 2018). Nevertheless, one interviewee noted that increasing private hedonic use of AR and VR could provide a good starting point for their organizational use:

"I have used VR for gaming, and it is actually an exciting experience. I believe that these technologies can be also beneficial in industry, if we make good use of them. [...] In our company, people are aware of these technologies, but they haven't thought about implementing them for professional purposes." Junior researcher, Cyprus

"I am very interested in innovative technologies and usually keep up to date with current developments. I have tested VR and AR personally, but it was always in a private setting. I own a stand-alone VR device which I use mostly for gaming. [...] I think both, VR and AR, hold immense potential and will only get better and more evolved with time." Software Developer, Austria

Many had also heard of the technologies or seen them on the internet in various different contexts (e.g. from ads regarding AR and VR) but had not yet used or tested these technologies personally. Overall, the professional

use of AR and VR was still quite limited in the interviewed companies, and their use still mostly focused on pilots and small-scale use as part of business processes, although in some organizations these technologies have started taking an ever-more central role.

"At the moment, and despite knowing that there are many other automotive suppliers working in the field, we haven't implemented any kind of activity related to VR. I could say that we are having our first approach to the technology by attending online conferences, trying to understand the real benefit." Plant manager, Spain

"Until three to four years ago, we did not have any experience with VR/AR/MR; then, we made an important internal decision which was to prepare our [business] for the challenges and standards of the 21st century; we started with doing basic research on what kind of virtual [approaches] exist in Europe and globally […] and decided to buy our first VR equipment." Director, Austria

Some interviewees also reported that technology and software vendors have demonstrated their solutions for many of the interviewed companies (e.g. training in VR where you can learn about machine installations and complete safety training scenarios). Long-term, many companies thought that it was necessary to stay up to date on AR/VR developments so that they could jump in when the expected value of these technologies becomes high enough.

"AR and VR are important technologies that can contribute to added value for the company itself and for its customers. You can't afford not to immerse yourself in them." Finance Director, the Netherlands

Besides the interviews, data was also collected on these issues via the survey. The following Figures 3-5 depict how aware the survey respondents were about AR and VR and how much they were currently used, as well as whether they felt there were significant limitations for using these technologies in their organizations. As we can see from figure 3, the majority of the survey respondents agreed at least to some extent that their organizations were aware of the potential of AR and VR in their organizational context.

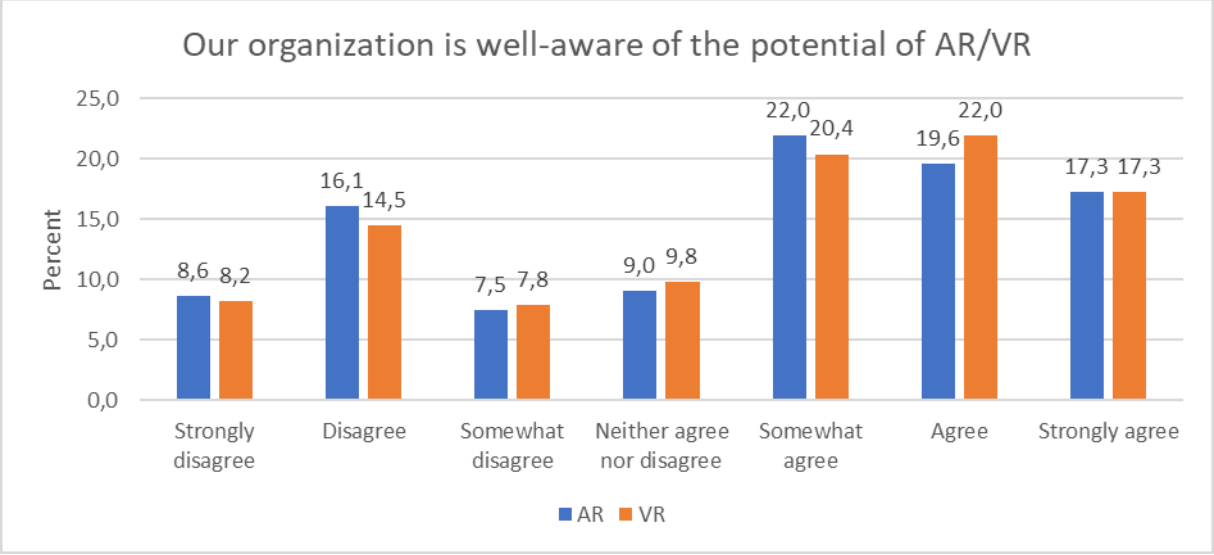

Figure 3. Our organization is well-aware of the potential of AR/VR

However, their actual use was still somewhat limited with around 60 % of the respondents noting that their organization does not use AR or VR at the moment. Moreover, around 25 % reported that their company uses these technologies either rarely or occasionally with around 15 % using them a moderate amount or a great deal. In fact, both technologies elicited very similar types of responses.

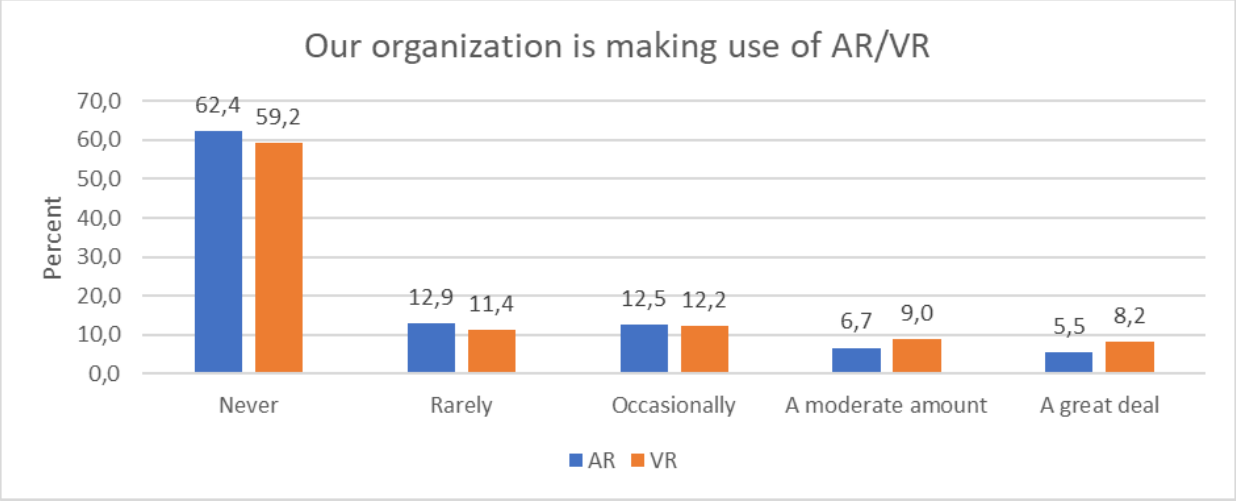

Figure 4. Our organization is making use of AR/VR

The respondents were almost evenly split (with around 35-40 % of the respondents either agreeing or disagreeing to some degree) on whether they thought that there are significant limitations in their companies to using AR or VR.

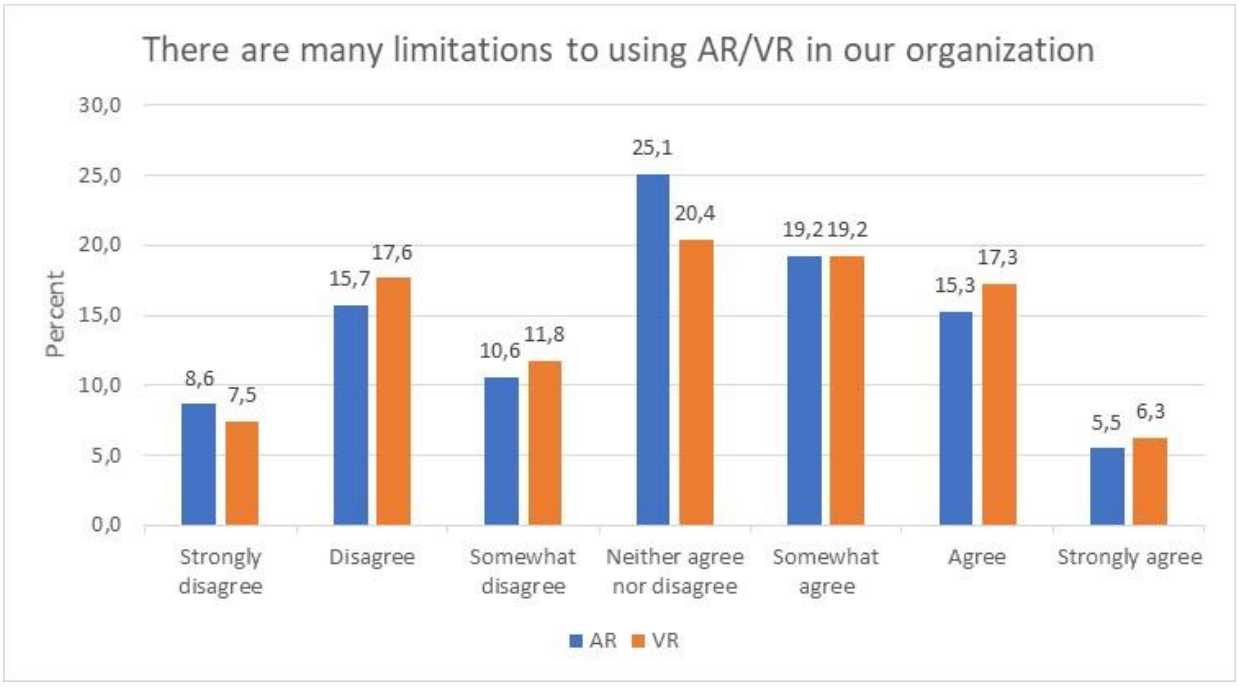

Figure 5. There are many limitations to using AR/VR in our organization

If we examine these numbers through the lens of Rogers' diffusion of innovations theory[3], the survey responses suggest that **the diffusion of these technologies is already starting to reach the early majority stage** (Figure 6).

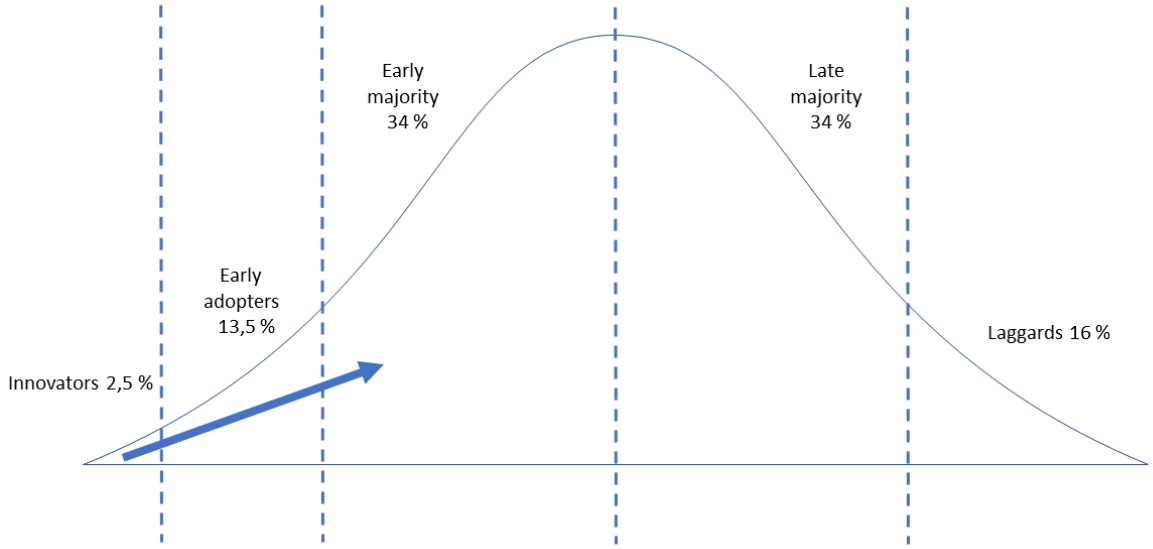

Figure 6. AR and VR adoption are starting to approach the early majority stage in European manufacturing SMEs

3.2 Terminology confusion

Many of the interviewees noted some terminology confusion in the industry context when it comes to AR, MR and VR. Many interviewees had not heard of MR, and those who had held many different interpretations about what MR actually was. Some interviewees viewed MR as a more advanced form of AR where the surrounding environment is mapped extensively and can then interact with the inserted digital content (e.g. a digital ball might bounce from the actual wall of a building instead of going through it) whereas some viewed MR to be a type of VR where elements from the real world have been brought into the user's view inside VR (e.g. the user can see his actual hands within a meter's length with a VR headset on). Some technology providers have created further confusion by calling their AR or VR solutions to be MR. This has apparently been done as part of a brand building function rather than trying to accurately describe what the technology is. Therefore, understanding where one technology ends, and another begins is quite difficult for those who are new to the subject.

However, **the main differences between AR and VR are largely understood by SMEs and these terms are more broadly recognized than MR**, which was clearly the most unfamiliar term of the three for many interviewees. Almost all of the interviewees understood AR technology to include the overlaying of digital content over the real environment. VR was understood to be an immersive technology where the real world is replaced with an

[3] Rogers, E. M. (2003). Diffusion of Innovations. 5th Edition. New York, USA: Free Press.

interactive virtual world. Out of these, VR is considered to be more understandable because its use always includes a head-mounted display (HMD) whereas the use of AR can be more broad-based and include both HMDs (such as Microsoft HoloLens) and smartphones (especially ARKit-compatible iPhones and iPads as well as ARCore-compatible Android devices as they make the AR experience smoother and more stable, although every smartphone with enough processing power can be used for AR). Moreover, different AR elements can often be included as part of other solutions. Next, we will describe the most important identified use cases for AR and VR.

4 Critical use cases for AR and VR in industry

The relevance of AR and VR can differ significantly depending on what type of activities the organization is engaged in. In the survey the respondents were asked to evaluate which technology (AR or VR, MR was omitted from the survey) had the most potential for their organization. As we can be seen in figure 7 below, **64 % of the survey respondents believed AR to have more potential for their organizations whereas 36 % thought VR had more potential for their organization.** This can likely be partly attributed to the fact that AR is a more broad-based technology that can be more easily used in many contexts whereas VR has more specific uses.

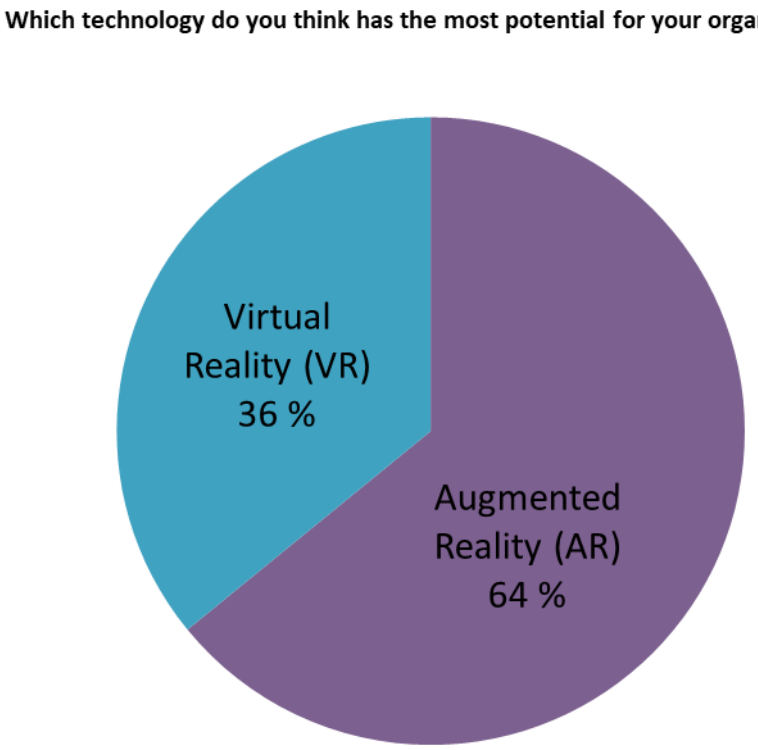

Figure 7. SMEs' perceptions on the potential of AR and VR in their companies

In the following sections, we will go over the most relevant use cases for VR and AR that were identified in the interviews and the survey. Figures 8 and 13 display a word cloud of the most common use cases that were

mentioned in the survey. **Overall, the identified use cases focused on marketing, design, training, information retrieval, remote support, and collaboration.** The use cases of VR were clearly seen to be more focused on the initial product phases where nothing physical yet exists whereas AR was seen to be more useful in the later product-cycle phases where different digital information can be presented in relation to existing physical assets.

4.1 Existing use cases and tangible examples of VR in industry

Figure 8. Word cloud on the most prevalent VR use cases from the survey

4.1.1 Design review and collaboration

Integrating complex design assets and visualizing them for a multi-faceted group of collaborators and end-users was seen to possess great potential for VR. **The higher immersion of VR was seen to help the users better understand the digital design model and thus make it easier for them to give feedback and comments on how to improve the design.** Some of the interviewed companies had done some pilots in this area and had gotten positive responses from the participants.

"I do have the feeling that this is something that we should be involved in developing [VR]. Especially when it comes to how we present our projects to our clients and end-users. It brings a certain aspect into it that will certainly be of interest. It's somewhat difficult for me to immerse myself into it [the end-user experience] because I'm so deeply involved in the planning that I know it so well. But the client or user likely doesn't know the plan so well and they could then visualize [in VR] what they want in their mind. It's certainly an impressive experience when you can get right inside the plan." Architect, Finland

One interviewed company was planning to pilot VR in the actual design process in an upcoming project and examine whether they can get to the final version of the plan quicker by iterating on the plan early and often in VR. Making alternative options of the design for viewing in VR is still seen to be a bit too much work to make it useful, although different parametric and automatic design features that are increasingly prevalent in many

design software could make it more feasible. However, even though the more accurate visual simulation provided by VR was seen to provide value, the comfort of VR headsets was seen as a possible issue in more extensive use.

"I could imagine there would be many benefits from this in many projects, you get that wow feeling and a feeling that you're really participating." Architect, Finland

"We notice that customers already like the current simulations on their phone or PC. The question is what the glasses will add, they still feel uncomfortable and awkward for many people. You do notice though that customers, especially non-technologists, can empathize better if a simulation is as realistic as possible." Head of Engineering, the Netherlands

Figure 9. A person examining a digital design in VR (Photo credit: Gorodenkoff/adobe.stock.com)

4.1.2 Error detection

Another interviewed company was using VR to visualize CAD designs in order to evaluate their manufacturability and to detect assembly issues in an early design stage, which would prevent expensive redesign cycles. This was done with an HTC Vive as a single-user experience, or by projecting the design on a wall for a multi-user examination with 3D glasses. This was identified as a key strength of VR as fixing design issues while the design is still in a digital form could create significant cost savings.

"With the HTC Vive application, colleagues have experienced the added value for the design process and so they've become more and more motivated to use VR in the evaluation process of machine design." Advanced Manufacturing Engineer, Belgium

4.1.3 Remote collaboration

The previous company was also using VR to get clients from all over the world to work together in real time with their VR solution. They also explained that they can display their 3D design file immediately in their VR solution without any time-consuming and laborious data format conversions. Other interviewees also noted the potential of VR in fostering remote collaboration, especially in the context of ever-increasing remote work.

"Thanks to this VR application the number of rework cycles had been reduced significantly." Advanced Manufacturing Engineer, Belgium

Figure 10. Users reviewing a digital design in VR. Remote users may also participate in the same session (Photo credit: Gorodenkoff/Shutterstock.com)

4.1.4 Marketing and sales

Another prominent use of VR was seen to be in different marketing and sales functions. For example, one company was presenting new building designs in VR to their stakeholders in the initial marketing phase to give them a better visual idea of what was being proposed. With this approach, the company is trying to see if it provides benefits for the stakeholders to see the upcoming product in 1-to-1 scale in VR rather than as 2D drawings or as a 3D object on a computer screen. However, the interviewed company was still unsure whether VR has had a decisive effect on clients' purchase decisions. In any case, AR and VR were seen to provide excitement and create a 'wow effect' for the clients which can help a company differentiate itself from its competition.

"When we've done workshops at our office, the time that has been spent moving in the virtual model with the [VR] glasses has still been quite short, and even though the comments have been really positive, the benefits are not yet so clear." VDC Manager, Finland

"However, through my experience I believe that these technologies can be a great marketing tool and they have the potentiality to increase our sales. In France, the public at the exhibition were very excited with it; I witnessed it." CEO, Cyprus

Figure 11. VR use in marketing at an exhibition event (Photo credit: Stephan Sorkin/Unsplash)

VR was also seen to provide opportunities to offer a wider scale of the company's products for review at industry fairs and other marketing events. Many manufacturing companies offer numerous different products of various different sizes which makes it impossible to present them all physically for clients at non-company premises, but this could all be easily achieved with VR.

"Even though we have machines with us at industry fairs, we can't of course bring them all with us because of transport and fair space costs, so in that sense VR could be a good addition so you could have the whole fleet in line and check all of them out to see which interests you the most." Work Planner, Finland

4.1.5 Training

Training employees was also identified as a relevant use case. **Hazardous situations that would not be feasible to implement in real life can be played out in VR simulations**. For example, fire safety training or instruction on handling hazardous chemicals could both be performed in VR with no risk to the personnel. **Language barriers would also not be as significant of an issue in VR training as the training is more visual in nature.**

"We would be highly interested in an app on work safety, because certain principles (safety clothing, work organization, communication procedures, safety distances, choice of the right tool, safe operation of machines etc.) could be trained well via VR. In addition, our employees come from many different countries (mostly from Eastern and South-Eastern Europe) and do not always speak German well. Strongly visualized (and less language-based) training would be an advantage for them, too!" Development Manager, Austria

"Also, regarding health and safety, these technologies might be useful for interactively engaging our employees in managing risky conditions in dangerous situations. Previous virtual examples might keep them alert at all times and lives could be possibly saved." Manager, Cyprus

Another identified benefit of VR training was that these **dangerous situations can also be made to be quite realistic which cannot be done in real life due to safety and cost issues.** They could also be used to perform impossible or time-costly tasks, such as quickly disassembling a motor into its component parts for review.

"For maintenance, for example disassembling a motor, it would be very cool if we had some VR stuff on that. You could circle around the motor, even if it was in video format, but that it would show how you disassemble and assemble it, […] it would be much more descriptive than a basic 2D video." Work Planner, Finland

"With VR we want to give the operator the opportunity to be trained in an "offline" environment on the management of the machine, the system, and its maintenance." Innovation manager, Italy

Figure 12. A person training in VR (Photo credit: XR Expo/Unsplash)

However, one interviewee noted that the skill transfer from VR training to real-life was not completely straightforward, even though some skills can be learned in VR. Moreover, the **VR training needs to be sufficiently realistic to enable skill transfer. Overall, the sentiment was that VR cannot completely replace real training, but it could be used to complement it in different ways and give a place to initially test new devices and tasks.**

"During the VR game, a user can start flying within a minute and gain serious knowledge within 10-15 minutes of experience. However, this cannot be comparable with the real training and real flight. Such a thought would be naive." CEO, Cyprus

"From a technological point of view, the solution was very interesting, but it did not have those details that are necessary to train a welder." Business innovation developer, Italy

4.2 Existing use cases and tangible examples of AR in industry

Figure 13. Word cloud on the most prevalent AR use cases from the survey

4.2.1 On-site visualizations and marketing

With AR, some of the interviewees were testing to see whether presenting new product designs in the actual context (e.g. building site) or presenting their products at industry fairs would create benefits because often the products are so large that it is difficult or costly to create real-size mockups or transport the products to location. This was seen to also be possibly beneficial in presenting modifications to existing assets (e.g., in building renovations). These options were seen to be easier to use for older user groups because you only need to view the scene via a smartphone or a tablet rather than in VR. This was seen to be easier in ad-hoc situations or with stakeholders who would only use the AR solution rarely. Those who want to have their hands free could also use an AR HMD, such as HoloLens. The choice of whether to use an AR headset or a smartphone/tablet for AR therefore heavily depends on the use context and the preference of the users.

Figure 14. Visualizing the inner components of a product with AR (Photo credit: 3DQR)

4.2.2 Remote support

In the operation phase, **guiding the maintenance personnel to the site and offering remote post-sales support and problem diagnostics were identified as a primary use case of AR by most interviewees.** One interviewed company had also been using AR to remotely supervise machine installations that are being done by distributors. Besides the financial and time savings brought about by remote AR support, the travel restrictions brought about by the COVID-19 pandemic have further highlighted the necessity of providing remote support services to customers.

"In terms of our business, I could see potential for AR/VR as a solution for remote maintenance. Once our products are installed, we offer after-sales support to our clients, the technical support to our clients could incorporate remote maintenance and use AR as a technological solution. We currently use remote desktop applications to support our clients, and this could be complimented with AR, particularly in the initial analysis of minor or major malfunctions that can occur and estimating the repair effort required. This could lead to savings in remote maintenance in the long term." Senior Key Account Manager, Germany

In maintenance, the focus has still been more on smartphone-based AR. In one company there have been talks with maintenance crews about HMD-based AR but they had identified several everyday issues with them that

hinder their use (e.g., where they would be stored, are they carried with you, and are there enough benefits compared to current methods). These practical reasons are why **smartphones are considered to be easier for AR use in the short-term because the employees carry them on their person anyway.** Moreover, the employees often receive new smartphones every few years which will likely have more advanced AR functionalities than the previous generation of smartphones.

Figure 15. Remote AR support with a tablet (Photo credit: Zapp2Photo/Shutterstock.com)

"If we have a machine in the US and a mechanic who doesn't have much training and you try to guide him on the phone, it would of course bring much to it if you could get the info to them via AR. "Check that wire, how's that connection, that cable, those soldering and so on"." Work planner, Finland

Another **clear benefit of these remote AR collaboration solutions is that the AR software is self-contained and does not need to be extensively integrated into other organizational information systems.** This was seen to lower the barriers for adoption because many companies have had significant problems in integrating their various information systems in such a way where they would have easy access to all of their information from a single source.

Language barriers also often create problems when you try to guide people remotely on the phone whereas with AR things could be demonstrated more visually. The chance for misunderstandings is also diminished when both of the collaborators have a better shared understanding of the issue via AR-annotated video collaboration.

One interviewee noted that AR could bring a lot of benefits in maintenance because right now when a machine breaks down somewhere, it is usually shut down for days or weeks. This is especially relevant when the

company's products are sold worldwide because once they have travelled on site at their own expense, it then usually also takes a while to locate the fault. **Checking the problem initially remotely via AR and identifying the main issues before you visit the site was thought to speed up maintenance.** In project-based work, the importance of these kinds of self-contained AR solutions increase further because all products are unique.

"We have been working on remote installation for a quite a while now. With cameras on the spot where it happens and a team that does the work from a completely different place. There were always all kinds of objections to really make it work and a year ago we couldn't handle them. But under pressure [COVID-19] everything liquefies. If I wanted to help my customers, we had to switch to remote installation and service. It's our most radical innovation ever." Software Engineer, the Netherlands

However, **the specific context of an SME's operations might limit the opportunities for providing remote maintenance support if, for example, the company's products are installed underground or in other locations where it is difficult to get internet reception** (however, some AR remote maintenance apps have been specifically designed to be used in these kinds of difficult conditions, e.g., DeltaCygniLabs' Pointr). Legal standards might also require that only qualified professionals can perform the necessary repairs.

"Another challenge in adopting AR for remote maintenance support would be that often our security hardware products are located in basements or underground facilities. In these locations or these parts of the buildings there is often no WiFi signal, often not even mobile telephone signal, making any kind of remote maintenance very difficult if not impossible. Furthermore, our business is dominated by German industrial standards (DIN), in relation to parts and components of all our products. Often in the repair or maintenance of our equipment, only fully-qualified experts may undertake any repair or maintenance of our equipment, due to these industrial standards." Senior Key Account Manager, Germany

4.2.3 Contextual information access

Presenting contextual information about various devices (e.g. IoT devices) with AR was also identified as one of the most potential solutions for AR. For example, a user might be able to easily access and view the maintenance information relating to a machine by reading, for example, a QR code that has been attached to a machine.

"A potential field for applying AR in our business would be on the one hand in our warehouse, where workers would receive information about specific parts, how many are left, in which machines they are used etc. On the other hand, a very handy field of application would be for our customers if they could look at their machines through an AR device, they could be informed about specific parts as they look at them, so they would know immediately which parts to order and which error they need to report […] The easiest would be an AR app for mobile devices (and usable on many different mobile devices) which must feature a camera. Clients would look at their machine through the lenses of the camera and app on their device and get additional information on the machine (brand, year of assembly, specifications, etc.). Most importantly, they would get information on the particular parts and they should have the chance to order spare parts through the app." Clerk, Austria

If the company does standardized product-based work, it was thought that a company could create AR solutions which for example have checklists for the most likely problems that are encountered with each product. However, one interviewee pointed out that the production runs for these products must be sufficiently large for the investments into AR to be profitable. **Creating AR maintenance apps which could pull up the relevant instructional videos and pictures was also considered to be an interesting possibility. It was seen to make it**

easier for employees to carry out their tasks if they could see the end result or step-by-step instructions on how the installations are made. One interviewee also noted that various gamification techniques could be embedded into AR/VR solutions to also make work more fun.

"Certainly for SMEs, immersive technology developments must come from specialized suppliers. What we are looking for is cost-efficient plug and play solutions." Director, the Netherlands

Figure 16. Presenting contextual information via AR with Microsoft HoloLens. (Photo credit: monolply919/adobe.stock.com)

4.3 Use cases are still in their beginning stages in SMEs

More broadly speaking many of the use cases in SMEs are still not as advanced as the technologies currently enable. This was also attested to by one of the interviewees who did a Master's thesis on the current possibilities of using AR, MR and VR in industry. Many issues relating to adoption barriers slow down the adoption of these novel solutions. Some interviewees also noted that they could not immediately think of any relevant use cases. This might primarily be due to the novelty of the technology and the lack of knowledge about how they could be used.

"Too often this technology is still seen as science fiction, too innovative and risky, not being actually functional." Vice President, Italy

Moreover, once these solutions are adopted, they would necessitate significant changes to the organizational business processes for them to create value. Many interviewees noted that **AR and VR cannot just be additional ways of doing things on top of the old ones.** One interviewee noted that the most important thing to understand is what the aim is with using these technologies and what they enable people to do differently either by

themselves or with others. However, revamping organizational business processes might also create resistance towards adopting these technologies. Many companies also stressed that the solution needs to be proven to work, as most SMEs might not have the resources to try anything too risky.

"It takes quite some time for new things to land in the organization. When you start working with AR 'from scratch', you will have a hard time dealing with the development costs and building a solid organization around it. What we were looking for was an accessible solution that was proven to work, rather than looking for all kinds of technical possibilities." Software Engineer, the Netherlands

Next, we will examine various organizational, technological, and external factors which were seen to affect the adoption of AR/VR in manufacturing SMEs.

5 Organizational issues related to AR/VR adoption

5.1 Upper management realizing the benefits of AR and VR

In many of the interviewed companies, upper management was reported to be aware of AR and VR, but their use is not being actively promoted yet. However, AR and VR were widely reported to be areas that need to be paid attention to. Many interviewees noted that upper management is really focused on what practical benefits can be gained from AR/VR, but their attitude towards these technologies has been generally quite positive.

"Our management is generally aware of AR and VR as these technologies are mentioned everywhere nowadays. However, nobody in the top management is promoting the use of Virtual Reality or Augmented Reality currently. They accept that some departments are thinking about VR or more likely AR solutions, but the management is not facilitating or promoting the adoption of these technologies in our professional field yet." Clerk, Austria

"Our sales department should first know more about the opportunities and customer benefits of VR/AR/MR. What's already there? What are low-threshold and proven applications? What could we offer right now?" Service Manager, the Netherlands

"I know that the management has thought about AR and VR – it is almost impossible to not consider these technologies at the moment – but as far as I know there are no current projects in relation to them." Software Developer, Austria

In one interviewed architecture, engineering, and construction (AEC) company, the interviewee reported a big change in attitudes in relation to AR and VR once they visited a technology provider conference where the CEO had a 'eureka moment' there when he saw that it was now possible to store BIM (building information modelling) files in the cloud where everyone could access them and view them in VR through an easy to use interface. The interviewee noted that the general atmosphere towards XR solutions in general has been very positive in the company after the excursion.

"The CEO's view on these technologies has become much more positive, he's really taken this whole development thing as his own. He's been complaining that we've been talking about this for years and years,

(I've been working here for a year now), and we've just refined these things further but haven't yet gotten to the practical part yet. Now it's much more like "Let's take this app into use", "Show this to the guys at the building site and ask them whether this could be a good thing"." VDC Manager, Finland

Excursions to other countries and industry fairs were also seen to be important because they allow you to see the latest AR and VR developments and talk to other relevant stakeholders (software developers etc.) to get an alternative view on things. Overall, in most of the interviewed companies there was definitely interest from upper management, but one of the issues was in finding time for delving into AR and VR and in understanding how they could be used to renew the company's business processes.

"There's definitely interest [from upper management], but the problem is who really has the time to acquaint themselves with this and do research, that's the barrier." Work Planner, Finland

5.2 Lack of resources and personnel time for development activities hinders adoption

The lack of personnel resources for technological and business development was also more generally seen as a significant challenge in most of the interviewed SMEs. Many interviewees reported that most employees simply do not have the free time to come up with new ways of doing things.

"The pitfall however is that management doesn't free up time for the employee to delve deeper into this technology and to do some experiments. As a consequence, only the most basic features of the software are used and the other features remain unexplored." Advanced Manufacturing Engineer, Belgium

Many SMEs also do not have many inventor/experimenter types of people working for them who would have the time and the inclination to get to know the AR/VR providers and choose the right partner for their company. In many SMEs, all IT functions have also been outsourced so they do not have the know-how on how to adopt new technologies themselves. However, in contrast, many larger companies felt like they could implement AR and VR solutions on their own.

Because the personnel resource is already stretched thin in many companies, many interviewees thought that it would be much easier if there was an outside company who handles the AR/VR hardware and software installations. One interviewee for example noted that they could probably do these things themselves in principle because they have created software themselves in the past, but AR/VR would be an area where they would need external support to make the development more streamlined due to their novelty.

"We would need to purchase full equipment (hardware and software) and we need external consulting in order to know which equipment is best for our needs and purposes; of course, we also would need external support in case of implementing software updates or when new technical solutions are launched. However, we never order customized items or solutions, we strictly buy standardized equipment and services." IT and HR Manager, Austria

Another company thought that they would probably need training from an external source, and that the whole AR/VR solution should come in a ready-made package (as a turnkey package contract) with hardware, software, training, and up-keep all in one so the company wouldn't have to do much themselves. However, in companies

with technology-focused workforces, training the employees on AR and VR use was not considered to be a significant barrier for adoption.

"If the technical solutions are not self-explanatory and too complex to operate, we would also need external training and further education of our employees. But this should not be a big problem - we could afford it and since our employees are technicians, they should quickly acquire new knowledge and skills [...] Should we ever decide to use VR/AR/XR solutions in our company, I do not expect any problems in motivating our employees to learn these new techniques and to use them in their daily work. Our employees are technicians who are used to permanently deal with new developments; furthermore, they love "technical gadgets" in general." IT and HR Manager, Austria

5.3 Limited availability of AR and VR experts

One issue that many of the interviewees were facing was that it is still quite difficult for companies to find employees with extensive experience with AR, MR or VR. Most who have experience with these technologies are self-learned or newly graduated. The opportunities to study the use of AR, MR or VR in the higher education setting are also still quite limited. On the other hand, the younger employees who might have the experience and know-how about these technologies still do not have extensive experience about the core business of the companies, and as such they need to share information about these technologies with the senior employees who have a strong grasp on the core business processes.

"One of the problems we have is that our age distribution is such that we have guys like me [younger generation] and then there are supervisors that are closer to 60. To get them to use them [AR/VR], we have to balance for a while between two things; I handle the facilitating [relating to the use of AR/VR], and the other guy handles the construction management side of things itself, and then we try to share knowledge [about these domains] between us, because we still don't have people who can handle both." VDC Manager, Finland

5.4 Companies split in their ability to adopt AR and VR without external support

There were quite large differences between the companies regarding whether they could adopt AR, MR or VR independently without outside support. In one company, the interviewee was very experienced with the technologies which meant that they could buy and install the necessary hardware and software by themselves and train the employees on how to use them. However, he stressed that this is by no means the rule in the industry. Larger companies also often employ various experts who could help with adoption.

"I am very sure that my company would be able to integrate VR or AR without external support as we employ experts of all kinds. Nonetheless, if one of our business partners would be an expert or VR/AR supplier, I think they would collaborate as long as it is mutually beneficial." Software Developer, Austria

"Our organization is not able to start using AR or VR on our own. We are a metal manufacturing company and our main core activity is far away from such a technology, most of our technicians are specialized in metallurgical processes, so we really need external support for VR/AR implementation." Purchasing and Investment Manager, Spain

The possibilities for independently adopting AR or VR was also seen to depend on the size of the company. **If there are over 100 employees in the company, adopting these technologies independently would be a significant project whereas with fewer employees a few self-learned internal experts could more easily teach the others on how to use AR and VR.** Larger companies were seen to be more likely to have people who are familiar with the technology but getting it into everyday use with several hundred employees is a different thing to achieve independently whereas with small companies and teams this was seen to be easier. However, this required that the SME has the necessary innovator-type employees who could implement the adoption.

"Our company is a small, versatile, flexible company. We therefore do not have any major issues when adapting to a new technology form. Our employees are very tech savvy. As the manager of the company, I am aware that our company has to be up to date on the latest technology for use in training. Our customers demand this. Due to the dynamic and agile structure of our company, it is therefore very easy to adopt new technologies and work methods." Manager, Germany

"Definitely, the company could not build alone the system for using these technologies. External support and expertise are required. Most probably, a private company that is specialized on this topic, could also provide a tailored software platform for our company. Devices are always easy to find and training after some time can be done internally." Site Engineer Manager, Cyprus

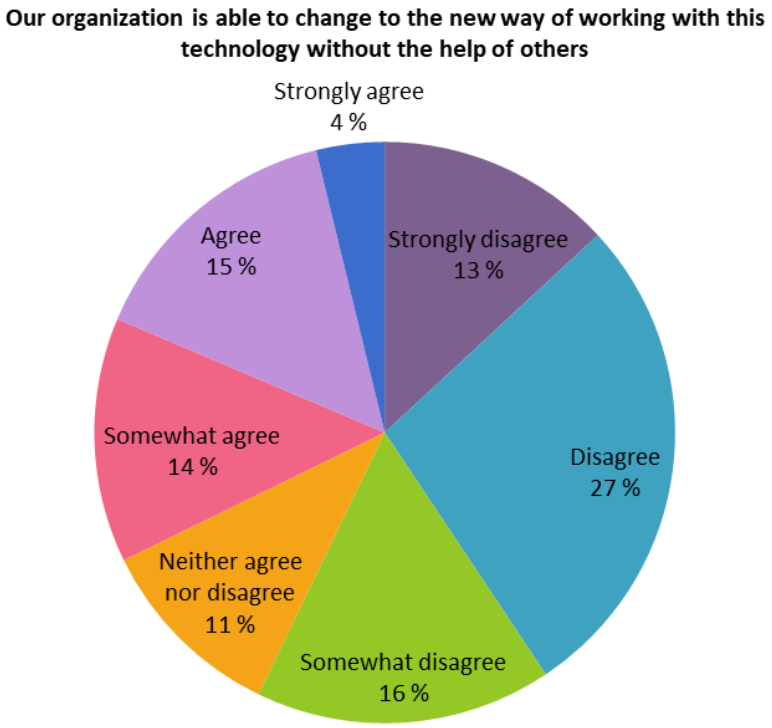

Figure 17. Our organization is able to change to the new way of working with this technology without the help of others

A majority of the survey respondents (56 %) also believed that their companies could not start using AR or VR on their own as can be seen from Figure 17.

In some smaller countries, the lack of access to local technology vendors can limit the possibilities to adopt these technologies and companies might be forced to seek out vendors from abroad (especially in niche use cases) which might not provide as much long-term support as a local company might.

"As a company, we are highly interested in using these technologies in the future. We have already developed some relations with a Brazilian company in France [during an exhibition] and we want to bring these technologies inside our company as soon as we are ready." CEO, Cyprus

5.5 The costs of hardware and software still pose limitations for companies

The benefits for AR and VR were seen to be evident by most interviewees, but their extent is still unclear, and it is hard to calculate their profitability. Accordingly, some of the interviewees also mentioned the cost of these technologies as a potential issue. For SMEs, developing custom software is likely to have a low ROI and many interviewees stressed that the solutions will have to be standard off-the-shelf solutions.

"I've thought about using these technologies at our company, but I don't know whether it is feasible, mostly because of the cost." Manager, Cyprus

The financial aspects of these technologies are also somewhat unknown to many companies; their lifecycle costs are not well known and the changes in operating costs and increased productivity and profits remain unclear. These issues are especially pronounced in conservative industry sectors.

"Our company is operating in a conservative market, and therefore the company and management are conservative in any investment in technology such as AR/VR. There is also the question of cost, the impression is that this technology is very expensive to purchase and very expensive to maintain and operate. The return of investment is not yet clear nor persuasive." Senior Key Account Manager, Germany

"As every company, I would like to see if these technologies can really increase productivity and reduce costs." Site Engineer Manager, Cyprus

"I think it's lack of knowledge about this technology itself, maybe its cost and the complicated equipment" Chief Developer, Estonia

The nicheness of the company's industry might also limit the opportunities in using these technologies.

"Our company's culture will not be an obstacle for an effort to introduce these technologies. We are generally driven by innovation. Maybe the cost will bother but if they are proved to be beneficial, it will not be an obstacle either. I think the most important barrier is the lack of applications and benefits that these technologies might bring, because of the specific activities of our company." Junior researcher, Cyprus

However, in one interviewed company the ROI on their new AR solution proved to be extremely high and the investment paid for itself in less than one year. Their new app allowed their multilingual workforce to increase the efficiency of their time-sensitive product delivery significantly. This AR adoption focused on completely revamping a critical business process that was still using paper-based methods. Identifying high ROI areas for development is therefore crucial for AR/VR adoption. It is also likely that as companies start seeing examples such as these, interest in AR/VR will rise.

"The payback period of this AR implementation was shorter than one year! There were massive improvements in both picking speed and picking errors. [...] But keep in mind that these nice results were only possible after a thorough analysis of the product flow and the daily attention to all preparatory actions." COO, Belgium

5.6 University cooperation and industry associations provide a glimpse of the AR/VR future for companies

University cooperation was seen to be important in shining a light into the possibilities provided by these technologies in the future. One interviewee noted that they view their own development work to be more in the 1-3 year range whereas with university cooperation the view is a bit further in the 3-5 year range. Universities also provide good opportunities for testing the newest hardware and software before companies consider adopting it themselves. However, the opportunities to test these technologies were more limited in some of the interviewed countries, which severely increases the barriers for adoption as most companies will not likely buy these technologies before seeing what they can actually do in practice.

"Yes, we were able to test different hardware and software before we started with our VR/AR/XR engagement. With regards to this, our British cooperation partner was a big help for us; the same goes for a regional university of applied sciences which is specialized on industrial design, history and development; they have pre-selected and evaluated some best practice examples of VR/AR/XR apps from all over the world for us; after we have experienced them with our own equipment, it was easier to decide which way we want to go with our own apps." Director, Austria

"What made our life really easier was the fact that we linked our VR/AR/XR development as an organization with two EU projects in this field; this helped a lot to find and finance external consultancy and support from universities (mainly on content level) as well as VR/AR/XR companies (technical level)." Director, Austria

In addition to these findings, some of the interviewees also identified their local industry associations to be a good source of knowledge and testing. This was due to the fact that they were considered to have good practical knowledge in their industry domain.

"We could trust the local association of our sector on this because they know the nature of our work and we talk the same language. Also, the National Technical Chamber that usually organizes subsidized training programs can provide good opportunities to experiment with new technologies, as it is also comprised by scientists." Manager, Cyprus

5.7 Innovative organizational culture a necessity for AR and VR adoption and mitigating employee resistance

Most interviewees also saw an innovative organizational culture as a must if one was to adopt these technologies. Upper management must also be very open to new developments. However, it is not enough to just want to see new things but there needs to be eagerness to try things in practice. One interviewee noted that their employees have been interested in AR/VR every time someone has come to demonstrate their use in practice, which has later translated into more expanded AR and VR use.

"There was some ribbing initially from the other side of the office when someone put on the [VR] glasses, but then they came closer to check them out and put the glasses on themselves because they hadn't tried them earlier. Then there's been comments that someone had tried something like that earlier and how with the first glasses there was some nausea and they weren't very eager to try them out, but when they tried them out, they realized that these things have advanced quite a bit and the nausea wasn't there anymore. Only thing they always think about is where the benefit comes from with these, what's the business side of them, and why we should start using them." VDC Manager, Finland

However, one interviewee noted that many still do not understand how they can be used in the business context. It is unclear whether better demonstrations are needed or if the company needs a better internal digital vision. **Resistance from employees was seen as an issue, especially with older employees.**

"Although I see huge potential for Augmented Reality, I am unsure of how our employees, and our training program attendees will embrace the technology." Manager, Germany

"Older workers are not familiar even with old and well-established technologies. I do not believe that they would easily embrace new technologies." Manager, Cyprus

It was therefore seen to be crucial to involve them in the AR/VR development from the start so that their concerns can be taken into account fully as one interviewee noted:

"Older employees were a bit skeptical about this technology [AR], but they have been consulted from the start, resulting in two equivalent systems they can choose from (Vuzix glasses or tablet) and finally, the whole technological change has been accepted and turns out to be successful today." COO, Belgium

Giving extra training to older employees would be necessary in many companies because often times there are still deficits in their IT skills, although many interviewees noted that there is a lot of variance and older employees are by no means a uniform group. **Training the employees extensively in effective AR/VR use was also deemed to be important because the ownership for the AR/VR solution eventually needs to be transferred to the business unit for them to take the reins.** One interviewee noted that if technology support personnel is always available, the learning and ownership doesn't get to the level where it should be, and this would make it more difficult for the business units to take responsibility for the new AR/VR functions. Luckily, many of the AR and VR solutions are quite easy and quick to learn, especially when it comes to their most important features.

"It varies a lot [level of IT skills], but I'll straight up say that there are some [people] in here who don't care one bit about these things [AR/VR]." Work Planner, Finland

"Regarding the skills of the personnel, I think it is clearly a matter of training. They are all able to use these technologies, no talent is required." Site Engineer Manager, Cyprus

Basic human nature and the **bias towards preserving the status quo were also identified as possible barriers towards adopting these technologies**. The health and safety of the employees was also identified as an area of concern. For example, in one company the designers use CAD for 8 to 10 hours a day. This made the interviewee question whether it would be possible for their employees to wear a headset this long without experiencing physical symptoms.

"There is also the issue of health and safety for our employees. Our designers use CAD for 8 to 10 hours a day. Would it be possible for our employees to wear a headset for 8 hours without experiencing dizziness, nausea etc.?" Business Operations Manager, Germany

"Sometimes, we unconsciously think that: when something works, what is the reason to change it? Personally, I believe that this is a wrong mind-set, but in our job it happens. So, somehow the culture of the organization could be a possible barrier." Site Engineer Manager, Cyprus

However, **in many companies the COVID-19 pandemic has proven that most employees can change to a new way of doing things** (e.g. communicating via Teams or Zoom) **quite easily in the end although there is naturally always some initial resistance. Once the managers and employees see the actual benefits, opinions were seen to change quickly.** Similarly, once they are able to present the benefits of AR/VR in the proper way, the interest was expected to be there.

"I don't think that employees would resist using AR or VR as we are used to working with innovative concepts and technologies. The main requirement is that the adoption of such technologies must be significantly beneficial to the persons and departments involved and economically viable for the company as a whole." Software Developer, Austria

According to the survey (Figures 18 and 19), **most respondents believed that their employees did not currently know how to use AR or VR or know where they could be used. This also highlights the importance of raising awareness** and providing the necessary training on AR and VR use.

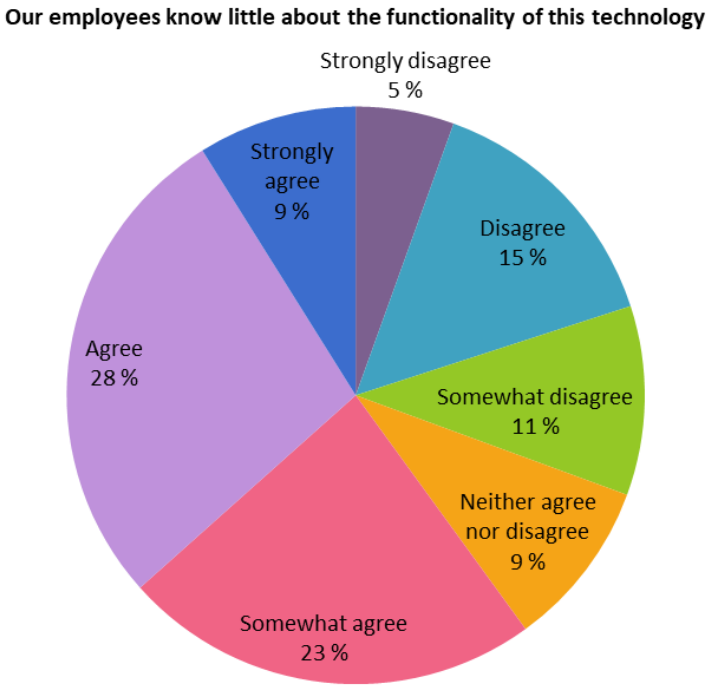

Figure 18. Our employees know little about how to use this technology

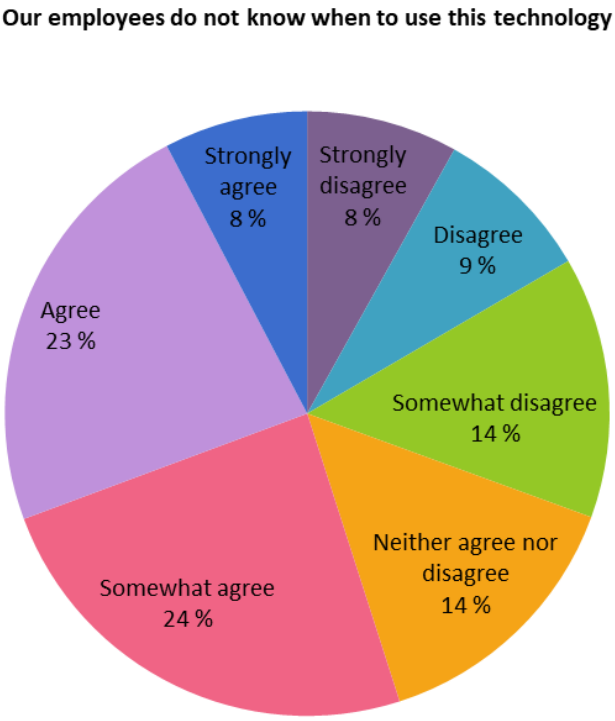

Figure 19. Our employees do not know when to use this technology

However, in many of the interviewed companies, most of the new employees are in their twenties so there likely will not be much resistance towards AR or VR because they were considered to be native with many digital technologies.

"Yes, our employees love to use these technologies. One can also say, it is a part of their profession to be interested in such kinds of innovations because they need it for their own job. However, you never can force anybody to be interested in or be open towards innovations … but I am very relieved that all of our staff are open-minded and engaged in that way." Director, Austria

"[Where AR/VR could be used] Especially in training new employees, they're in their twenties–most of them–so they're very open towards these things and we could probably get a lot out of this [AR/VR]." Work planner, Finland

"Actually, we did not have any real barriers to overcome; the decision to improve our services […] with VR/AR/MR apps were taken on [various] levels; this means we had all important stakeholders on board, right from the beginning. We were a little bit surprised how low costs for basic hardware and software was, so money was not a problem. Also, our staff was enthusiastic about this idea; since all five persons working for [the enterprise] have a good level of education, they already had appropriate technical and general knowledge and skills to learn working with the hardware and software quickly." Director, Austria

5.8 The importance of facilitating technology adoption

It is also crucial to design the initial AR/VR testing and adoption situations to be as engaging as possible. In one interviewed company, the adoption process usually starts with a collaborative session where everyone gets to try the new AR/VR solution. Then a head user is named who delves into the technology more deeply and takes ownership. The other employees can then consult the expert if they run into problems. The interviewee also explained that adopting AR or VR can be even thought to be exciting when compared to other IT systems because you get to use AR and VR in practice, and you get to see things differently than before. Often when you test AR or VR, you can skip the slide show entirely and get right to business by turning on the device and getting people to use it straight away. The interviewee also reported that people are often very eager to test AR or VR when you compare to other software adoptions. **AR and VR adoption are somewhat special in this sense when compared to other IT solutions because it is much more hands-on.** However, one challenge here is that the hype that has been created around AR and VR in recent years can often make meeting user expectations difficult or impossible, which can decrease interest. Due to this hype, there is also a lot of misinformation floating around regarding AR and VR. Managing expectations is therefore also an important area to pay attention to.

"There would probably be some initial resistance from the older workers, but I believe the younger ones would jump on eagerly. In our own production the training would mostly focus on the younger guys, so I don't believe there would be any big problems." Work Planner, Finland

As can be seen in Figure 20, a significant majority of the survey respondents still deemed it worthwhile to adopt these technologies despite the challenges that might be faced in their adoption.

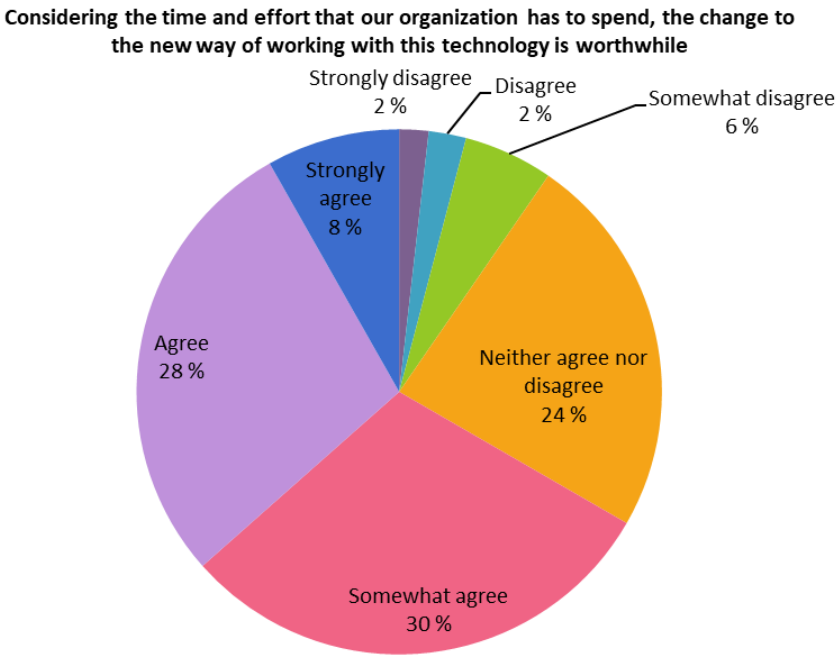

Figure 20. Considering the time and effort that our organization has to spend, the change to the new way of working with this technology is worthwhile

6 Technological issues related to AR/VR adoption

6.1 Technological install base and network effects for AR and VR still limited

A crucial short-term issue that came up in the interviews was that the necessary install base and network effects are still often not in place for AR or VR. For example, in one company they had thought about creating a VR environment for remotely maintaining machinery, but this idea was dropped because their clients would then also need VR glasses which would raise costs for customers. It was therefore unclear if there would be value in that approach over video calls. Many interviewees also reported that AR and VR applications were either not yet available for their specific industry context or there were only a few not fully polished applications available, which had made it impossible so far to implement these technologies. In this case, one interviewed company had tilted more towards using AR for remote maintenance support because these solutions could be implemented with the already available smartphones that are currently in use with various stakeholders. However, even with smartphone-based AR, smartphones with the most advanced AR functionality are still not widely in use, although this problem was seen to remedy itself automatically over time when new smartphones are purchased.

"I myself have used VR equipment for two or three years and believe that it has great potential, but unfortunately there are still too few applications for the industrial sector of my company. [...] I had great hope that somebody in the VR community would have provided apps for our profession to improve safety at work. I know some apps for [our] industry, but unfortunately, they are not suitable for our needs (not fully developed, not that focused on occupational safety)." Development Manager, Austria

6.2 Wide array of available AR and VR hardware in use in companies

The interviewed companies had been using various different AR and VR hardware. Some of the most frequently mentioned wired VR glasses were the HTC Vive, Oculus Rift S, Samsung Odyssey, Valve Index and the Varjo VR glasses. Oculus Go and Oculus Quest were the most frequently mentioned stand-alone VR glasses. One company had also tested the smartphone-based VR headsets (i.e. Google Cardboard and Samsung Gear VR) when they first came out, however, these solutions left them with an initial negative impression because they could not handle demanding content and the solutions didn't really work well with other software, which made their efficient use difficult. This led this interviewee to note that they had felt that the hype for VR was more intense a few years ago and it has since hit a lull. However, after seeing the newest hardware and software solutions, it became evident to them that there has been significant progress in remedying these issues.

"It all culminates into how easy it is to use. It somehow goes so much hand-in-hand that if you feel it's difficult and cumbersome, its use easily falls off." Architect, Finland

Overall, stand-alone VR glasses (e.g. Oculus Quest) were seen to possess the largest potential for wider VR adoption in companies due to their ease-of-use and lower price-point. These factors were seen to be crucial for many use cases. In certain use cases, like sales for example, it cannot take more than 30 seconds to get the VR headset up and running and get them on the client's head. Using 15 minutes to get the device working was seen to be a complete non-starter in these kinds of use cases because the focus has to be on the content, not the VR device. The more expensive options are also not always necessary. However, in use cases where absolute

precision and detail are needed (e.g. flight simulators), high-end VR glasses (e.g. Varjo VR-3) are certainly necessary.

Finding the correct balance between accuracy, performance, and ease-of-use in each use case is therefore crucial. Overall, wired VR headsets such as the Valve Index are seen as a sort of middle option currently because the Varjo glasses are still quite expensive and the Oculus Quest glasses are still not able to fully handle the most demanding content. However, the Oculus Link for the Oculus Quest is another interesting possibility because it allows the performance of PCs to be exploited when needed and for the headset to be used as stand-alone when necessary.

"I see that there's a divide [on what type of VR will be used]. For example, the design cases, work site and design meetings will use stand-alone [VR] because they need to be as easy to use as possible. The Quest for example, you pick up the glasses from the table and go straight inside the model, that use case is easy. The cost is also an issue, the Quest is cheap so it's possible to buy them for design offices and they're easy to work with. Then again if we want to sell something specific to clients, in that case it tilts towards the higher quality [VR] glasses. The competition can be fierce in some cases, then you want to get the most powerful technology which means the Varjo glasses." VDC Manager, Finland

When it comes to AR, its use in the companies has mainly focused on different AR-compatible smartphones and tablets as well as Microsoft HoloLens and Vuzix HMDs. The wide availability of smartphones and tablets were seen to provide the most likely avenue for AR use in the short-term. Moreover, as these devices are updated every few years, their AR capabilities were seen to increase automatically over time as well. Nevertheless, in certain cases where it is crucial for the user to have both of their hands free, AR headsets could prove to be useful. However, in one Belgian company they had also come up with a workaround for this issue by attaching a Velcro strap to the tablet or smartphone to enable handsfree use.

"At this point, pickers have two options: they can pick the products with the Vuzix glasses or they can use a tablet, which is attached to their wrist with Velcro fastening to allow for handsfree picking. The tablet works in fact in the same way as the glasses." COO, Belgium

6.3 Opportunities to test AR/VR seen as essential

Some of the interviewed companies have also been able to test different VR glasses that were still not widely in use (e.g., HP Reverb, Varjo, Valve Index, HTC Cosmos). Fairs, industry events, universities, and other companies were seen to provide good opportunities for testing state-of-the-art solutions. Technology associations and organizations focused on AR/VR also often organize events where new solutions can be experimented with. It is noteworthy that in each of the reported testing situations, only one set of VR glasses was available, so the companies have not been able to test multi-user VR. This is an area of development that many companies have been stressing, and technology providers need to definitely take note of this demand. The ability to test these devices in practice was generally identified to be essential, so that the companies do not have to buy these devices blindly.

"We would like to be offered a demonstration or a free trial before we use these technologies, in order to be sure about the results and if it actually produces profit for the company." Manager, Cyprus

6.4 Access to digital information seen as crucial for AR and VR adoption

Besides the new improvements in AR and VR hardware, the organizational information flows in the background were identified to be crucial for their adoption. According to the survey (Figure 21), around 31 % of the respondents disagreed to some degree with the statement that AR/VR could easily access data from their systems. These companies would therefore first need to ensure that their systems can actually be used in conjunction with AR or VR. **Many interviewees noted that the lack of digital assets that could be viewed in AR, MR or VR** (or their compatibility with these technologies) **had really held back the use of these technologies in many companies in the past.** Many of the interviewed companies were also still working on other digitalization efforts that could later enable the use of AR/VR in their companies.

"Well, we haven't started using VR technology yet because we are involved in other levels of digital transition directly related to production activities such as piloting artificial vision implementations, collaborative robotics, and ERP. We are aware of this technology and its benefits, but maybe [we will adopt VR] in the next digitalization step when we can have a clear view of the return of the investment, and when it´s globally tested in an industrial environment." Plant manager, Spain

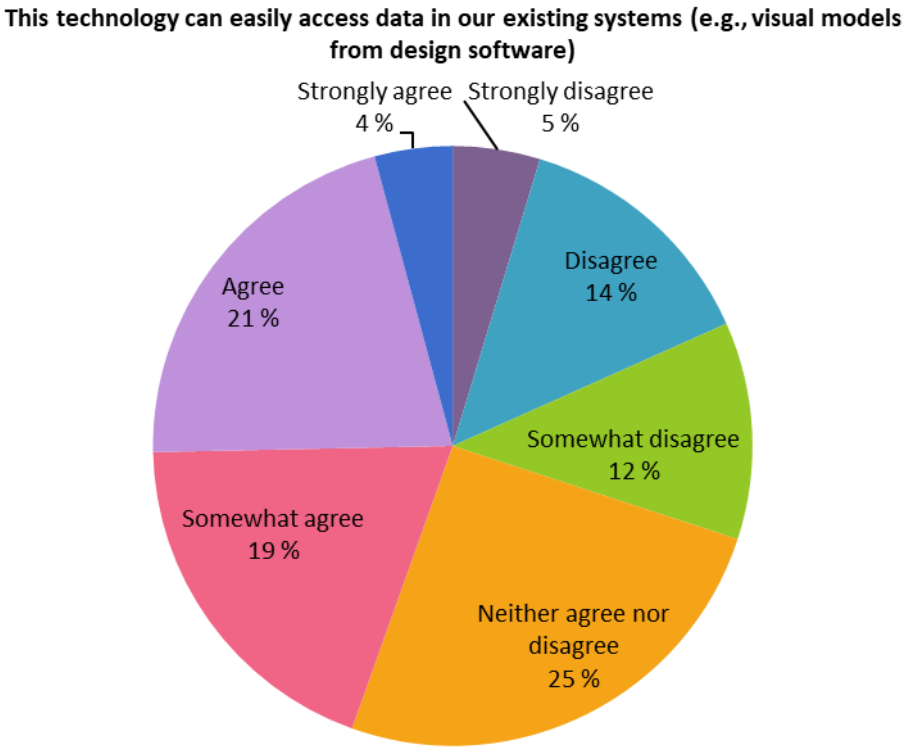

Figure 21. This technology can easily access data in our existing systems (e.g. visual models from design software)

Moreover, **although many of the interviewed companies had already transitioned to using various 3D design software, many of their earlier designs are still only available as 2D drawings. Integrating these legacy assets in AR and VR supported workflows was therefore seen to be challenging.** For example, in the AEC industry many

of the newly designed buildings have BIM models available, but much of the existing older buildings have very little or no digital information available about them. This means that for example an AR app that presents maintenance information to the user about buildings could only be effectively used in newer buildings.

"The issue with this technology [AR/VR] is the lack of compatibility and integration with current systems and CAD software." Business Operations Manager, Germany

"Our partner has worked on a case in which they use Vuforia from PTC with Microsoft HoloLens in which they load CAD data. This mixed reality application is used for quality control on truck engines. They don't use it in production. It was just a proof of concept by which they learned a lot about this technology. The biggest problem was to import CAD data into the module." Digitalization and IT manager, Belgium

Moreover, **different application programming interfaces (APIs) are important because these new realities *"don't just come about by themselves"* as one interviewee noted but need easy access to relevant information to be useful for organizations.** Knowledge about APIs and the related organizational practices are still not at a high level in many companies, and there are also problems in many companies in not understanding how opening up your data can create new business opportunities. In many of the interviewed companies, there was still a lot of work to be done in developing their business processes as many services are still very siloed and do not communicate with each other effectively.

6.5 Fast workflows between software and AR/VR ease business process integration

Besides access to digital information, **the workflows and pipelines between AR/VR and software and information systems need to be efficient. In this regard, one interviewee noted that seeing the workflows go both ways between VR and design software was crucial in changing the CEO's mind about VR.** Another important feature was the ability to create voice annotations in VR instead of typing the comments manually, which was seen to be much easier for users. However, this company has only been importing BIM models into VR for now, and no other content has been integrated in VR yet. A prime reason for this is that you can now get the BIM models into VR with a single-click. **Previously, companies had to do time-costly and laborious file exports between many different software before the model could be viewed in VR, whereas now the comments that are made in VR also go back to the design software (e.g. BIM360) easily.** However, it is still uncommon that the user could modify the model inside of VR, especially in the AEC context. On the other hand, **new solutions for real-time CAD model editing in VR have also recently begun to emerge (e.g., Mindesk VR).**

"Earlier the workflows have been more custom [for VR], so we've exported the model into something else, then something more was done to it in some other software, and only then it became viewable, and even then not necessarily in a multi-user setting. Whereas now when we have the model, there's a button which says 'View in VR', and we can then go view it with a group." VDC Manager, Finland

"Probably the use cases aren't always clear to the ones who create the VR software or sell them as services, they don't always understand what kind of things it would be used for or what our requirements are for such a tool. In that sense, for example, updating things is very difficult with certain solutions, even though it should be such that when you open the VR model, you could immediately do something when you notice that for example a hospital bed is in the wrong place or that these buttons don't work at all, that you could immediately change them to something different as in "Is this what you want?"" Architect, Finland

6.6 Previous software and information system choices can limit options

The previous organizational choices in information systems and software can have a decisive effect on whether AR or VR can be used in the company. For example, in the AEC context one interviewee noted that during the last year it became possible to easily view digital building models in VR in some of the more popular design software, however, with customized or tailor-made software the availability of these kinds of options was more uncertain. This type of path-dependence with a software that does not have the desired AR/VR functionality, or the necessary plugins can therefore limit their use. However, current AR/VR plugins already support many different design software and many interviewees noted that there are not as many problems in this area anymore compared to a few years ago.

"The ability to update [the model] has been lackluster and that's diminished our interest in using it. Because going from the ArchiCAD model to the VR model requires quite a lot of work." Architect, Finland

6.7 Facilitating AR and VR use important as the number of users increase

Practical issues such as centralized control of stand-alone AR/VR headsets with hardware racks (with cleaning and disinfecting and maintaining software updates) were seen to become necessary when more people use AR/VR, because maintaining the AR/VR devices can otherwise become chaotic as their numbers increase. However, many reported that it was still hard to find complete ready-made solutions for this. The importance of these factors has also increased with the heightened importance of hygiene due to the COVID-19 pandemic.

Being able to manage other users in VR has also been identified to be important in many use contexts, such as sales situations, so that the other users do not start wandering around the virtual environment uncontrollably. It's also important that you are able to join in VR with different devices (tablets, laptops etc.) so that all employees and stakeholders can still participate in the business process if not enough VR glasses are available or if some employees simply do not want to use them. Even though some of the interviewees were familiar with multi-user VR, it had only been tried in a few of the companies but was not in active use.

"Compared to watching something together on a screen, 2D or 3D content, well what's the benefit of VR if only one person is in there and gets lost there and doesn't know how to use it? With the social aspect, when you get several users in there simultaneously, perhaps a whole family, and then you drag them around in there, and they can even be there with different devices, then I think we could certainly start to get some benefits from it. Then it starts to deliver on what it's supposed to be." BIM/VDC Manager, Finland

6.8 Hardware sophistication and durability still pose limitations for use duration and certain use contexts

Another issue that one interviewed company had faced with AR helmets was their limited battery capability which made it difficult to use them during longer work shifts. Newer AR HMDs have improved on their battery longevity however so this barrier to use is being reduced.

AR HMDs are now also becoming more compact and robust which has made their use more feasible in many demanding use contexts (e.g. many AR HMDs can even be used at construction sites with hardhats). The robustness of headsets in general was still identified as a possible concern. Moreover, if the company operates

in difficult environments (e.g. dust and dirt), this was seen to pose challenges to employee safety as the visibility in the AR headsets might get blocked. The equipment (hardware) and devices also need to be very resilient to external conditions (e.g. high temperature, humidity, rain, chemical-proof etc.) in certain use contexts such as construction.

"From our point of view, we can't imagine having any issue becoming familiar with the software of this technology, however the hardware is a bit bulky and there is also the question of cost. This technology isn't extremely expensive, but it is fairly delicate and would have to be replaced regularly at mounting cost." Business Operations Manager, Germany

The discomfort that an AR or VR head-worn device might cause to the employee during work was also identified as a potential issue. AR solutions should therefore work with both AR headsets as well as with tablets and smartphones.

"This AR application has been initiated by management, but pickers have been involved in the introduction of this technology from the start of the initiative. Since some of them were not so keen to wear AR glasses, e.g. because they have eye problems, management worked out a tablet alternative in parallel." COO, Belgium

One of the main challenges with AR has been in fitting the digital information or the virtual model into the environment with high accuracy. In certain use contexts, the model needs to be fitted within millimeter accuracy, because 1 or 10 cm scale accuracy only provides "nice to know" information and cannot actually be used extensively for work purposes. One interviewee also explained that current AR applications seem to work well in a test setup, but they often do not yet work well on the "real shop floor". However, the interviewee was convinced that it is just a matter of time (2-5 years) before immersive technologies become mature enough to meet strict industrial requirements.

"The challenge has been that the everyday user is not that well-informed which means that it [AR] would have to be very easy to adopt to get any benefits from it, so there can't be any calibration or start-up requirements for it to be adopted at worksites. The expectations for AR at worksites are significant, perhaps larger than for VR, but the millimeter accurate positioning and getting it fitted quickly, that still requires work. I haven't seen such a solution yet." BIM/VDC Manager, Finland

"We have to be sure about the reliability and precision of these technologies before their use. Is the presented information and data accurate? There is no room for big mistakes in construction. Small mistakes can cost a lot of money." Manager, Cyprus

6.9 Future technological development will further increase the possibilities and ease of use of AR and VR

Developments in smartphones (e.g. how newer iPhones and Android-smartphones can 3D scan the environment) were seen to have increased the possibilities for AR overall because all of the necessary equipment for using AR is already in the field. One interviewee also noted that it is easy to test out new AR apps as you can simply download them from the app store. Moreover, new advanced chipsets (e.g., Snapdragon XR2) offer significant improvements for both AR and VR headsets and subsequent software development.

"In my personal opinion, sooner or later AR and VR will become natural tools in our daily life and work just like smartphones have become essential and broadly used in the past years." Software Developer, Austria

Many interviewees expected that it is likely that they would be using AR or VR in ten years, and many hoped they would start using them within two years. Most of the basic digital design aspects were quite advanced in many companies, and if you can give good arguments for why the company should adopt a system, there's usually money available for it. The COVID-19 pandemic might have also sped up these developments significantly as companies have to find efficient ways to work and collaborate remotely.

"I saw it [social VR] the first time a couple of years ago, back then I was still wondering what the benefit would be from this, but this world can now change to a virtual one in the blink of an eye [due to the COVID-19 pandemic], then this certainly goes hand in hand [with that development] so the need is certainly there in that regard." BIM/VDC Manager, Finland

"I don't know, the systems seem quite nice already, I'd say once we wake up to this reality…in ten years we'll be using probably one of these, and I'd wager it would be AR." Work Planner, Finland

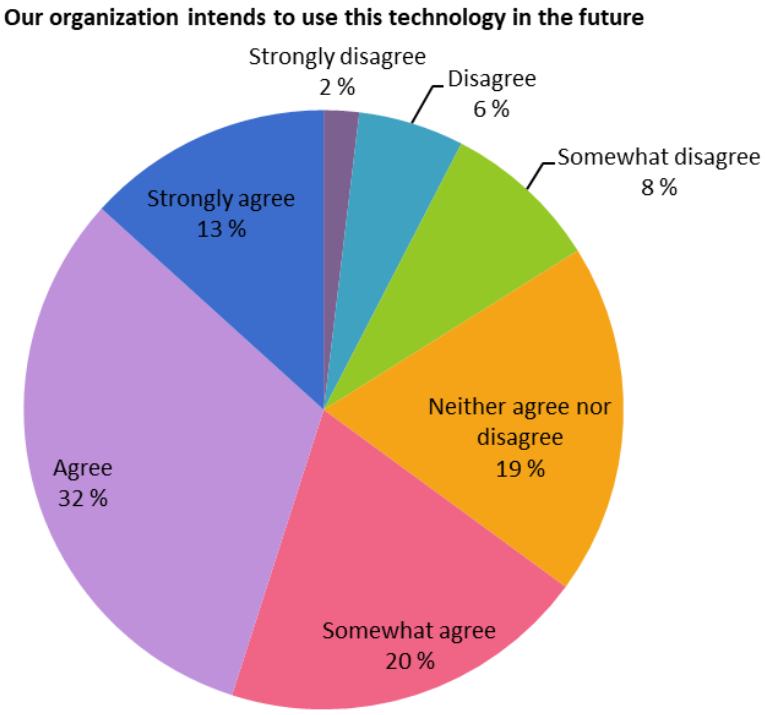

Figure 22. Our organization intends to use this technology in the future

Overall, a majority of the respondents (65 %) agreed to some degree with the statement that their company would use either AR or VR in the future (Figure 22). Only a small minority (16 %) disagreed with this view to some extent, although there was a sizable minority (19 %) who were ambivalent about whether these technologies would be used in their company in the future.

7 External issues related to AR/VR adoption

7.1 Most competitors still not using AR or VR

Most of the interviewees had not yet seen their competitors and other relevant stakeholders using AR or VR actively so most of the AR and VR developments in the companies have purely started from their own interest. One company also reported that many of their stakeholders use the same design software but are still not testing or using VR even though it is now possible in the software.

"This has purely come from our side [VR adoption], we still haven't seen any competitors using it. […] Certainly some are already using Enscape [VR-compatible software] for example, but they're still not using the [VR} glasses." VDC Manager, Finland

"The next industry fair is in two years' time I guess, so if someone is now starting to use these, you'd see it then. So, if no one else has nothing going on then, that might be a good time to think whether we should actually be the first." Work Planner, Finland

Companies are of course also looking to create competitive advantage from AR or VR, so even if some companies are already using these technologies (especially in internal company work), it is not likely that they would broadcast this fact widely to their competitors, whereas in customer-facing functions it might be easier to identify whether your competitors have adopted AR or VR. Moreover, innovative companies would likely move into using these technologies without seeing them in use in other companies first.

Overall, the level of adoption has been lower than was initially anticipated a few years ago. Many interviewees still noted that if they start seeing any positive examples of their usage, it will increase their interest towards adopting these technologies. However, at this stage many companies still do not know other companies in their sector that use AR or VR. One interviewee also noted that they would not immediately start adopting these technologies if their competitors started using them but would wait for longer-term confirmed results.

"Extended use of these technologies by competitors or relevant partners can influence our company to adopt them." Manager, Cyprus

Several interviewees also noted that the smaller companies often wait for larger companies to first adopt these kinds of novel technologies due to their higher resources and ability to take risks. Some of the interviewees noted that SMEs oftentimes monitor how larger companies are using these technologies profitably to identify how and where these technologies can be used most effectively in their SME context.

"The biggest influence of introducing these technologies are big leading companies. They usually lead innovation because they can handle costs and risks. This way, we will have an example of the performance of these technologies and then decide if we will use them. However, I do not know any competitor that uses them yet." Manager, Cyprus

"Because we are a small company, we do not have the luxury of making large high-risk investments. Any technology or new working methods we choose to adopt have to be well proven use cases. And if it requires a large investment then it must be well tried and tested." Manager, Germany

7.2 Customer readiness can act either as a barrier or promoter of AR/VR adoption

Another issue for larger AR or VR adoption also related to how the customers of the companies could use AR or VR. This was identified as a problem, especially for companies who operate globally as training their customers in using these solutions would be difficult. For this reason, many of these solutions were still considered to be more viable in internal operations.

"I think the most needed skill would be to train customers in using their AR technology to report missing or damaged machinery parts and to order replacements. This is also one of the reasons why the use of AR in our customer service is currently not considered economically viable. [...] The main problem with this is that our clients are located all over the world, sometimes in very remote places. Adopting AR technology does not happen overnight and requires some basic infrastructural elements." Clerk, Austria

However, some interviewees also noted that their customers are now demanding virtual models more and more, so this demand is also starting to swell up from the ground-level to management. The use of virtual models could then later be expanded with specific AR or VR solutions. However, in some of the interviewed countries, there were not yet any reports of customers demanding the use of AR or VR, so differences between countries in AR and VR adoption are likely substantial. Still, many companies will likely eventually adopt AR or VR once competitors have already started using it too in order to keep or gain new customers.

"Our company has to keep up to date on technological developments such as AR/VR. If we think our clients will move in that direction, then we must follow. In such a scenario it would be a customer-led approach. Our clients would provide us with a standard to which would follow accordingly to be compatible with their systems." Business Operations Manager, Germany

However, one of the critical issues for AR/VR adoption is the lack of hardware install base with clients. This means that currently companies can only use AR/VR internally or create facilitated AR/VR experiences for their clients and they cannot rely on the customers to be able to use AR/VR by themselves (e.g. via website) due to the limited diffusion of AR/VR hardware.

"I only know a company in the construction industry that creates 3D models for the client, to demonstrate the interior of the house before the construction. In these cases, I can imagine that these technologies can be beneficial because they proactively obviate possible changes that might cost serious amounts of money for the company." Junior researcher, Cyprus

Most customers are also still more keen to use smartphones or tablets rather than headsets, and there is still skepticism about using wearable AR/VR devices. Cultural differences between different countries were also identified as a relevant factor which can affect the adoption and use of AR or VR in the company.

"Especially in Italy the customer prefers to see the service person face-to-face, still physical meetings are preferred to solve problems." Vice President, Italy

8 Conclusions and recommendations

We will now summarize the findings of the report and give out recommendations regarding the adoption and use of AR and VR in European manufacturing SMEs. These conclusions and recommendations are based on data that were collected from 255 online survey respondents and 46 interviews with European manufacturing and industrial SMEs.

When VR re-entered the public consciousness back in 2016 with the Oculus Kickstarter campaign and subsequent release of the first Oculus VR headset as well as the competing HTC Vive headset, many companies were excited to see what it could do and whether it could provide actual benefits at this development stage. A similar thing happened with AR as the Google Glass and Microsoft HoloLens headsets were released. However, **due to the hardware being new, much of the software lagged behind, especially in the enterprise setting in relation to integrations with different information systems and business processes, as well as the ease and efficiency of pipelines between different software and information systems.** When companies first tested many of these devices, many of these functionalities were not yet highly developed which may have dampened their interest in adopting these solutions despite the initial 'wow effect' these novel technologies created for many users.

However, **AR and VR software have now started to catch-up to the potential provided by new AR and VR hardware. Many of the newer software solutions are now much more fully fledged and integrated with many relevant software and organizational information systems. Moreover, many of these advances have happened only in the last year (2019-2020), and consequently, many of the interviewed companies were not even aware of these possibilities. Companies should therefore take a renewed look into AR and VR** and re-evaluate whether these technologies can now provide more value and be more easily adopted to support business processes.

Naturally, **the relevance of AR and VR as technologies differs greatly between companies. In the survey, 64 % of the respondents perceived AR to have more potential for their organization while 36 % thought VR to be more beneficial for their companies. However, around 60 % of the respondents still reported that AR or VR was not being used in their companies. Approximately 25 % responded that AR or VR was being used rarely or occasionally with approximately 15 % reporting that they were used a moderate amount or a great deal.**

Overall, **VR can be seen to especially benefit companies which are involved in designing new products, because VR is especially relevant in those stages of the design process where nothing physical yet exists.** Designing in VR can save tremendous amounts of money in physical mock-up costs while also enabling faster iterations on the designs. Moreover, the immersion and one-to-one scale of VR provides benefits over designing in traditional 2D desktop environments as VR enables users to better comprehend the dimensions of the design. VR presents information to users in a more visually intuitive and understandable form when compared to many traditional methods that are currently in use. VR also enables people to participate in the design process from different locations which is especially relevant due to the disruptions and future uncertainty that the COVID-19 pandemic has unleashed upon the business world. This collaborative aspect of VR (i.e. Social Virtual Reality, SVR) and its role is likely to gain in importance in the future.

"A possible, interesting use scenario would be to create working environments to connect people while working remotely, especially in periods like the current pandemic (COVID-19). This will increase wellbeing, communication and collaboration between employees." Junior researcher, Cyprus

In most companies, VR is still mostly used with one set of VR glasses with the picture being shared on an external screen. Even though this already supports communication to a certain degree, **larger benefits are likely to be gained as multiple users can directly collaborate with each other inside VR.** New SVR software solutions have also begun to emerge in the last few years. Despite the impressive visuals and new ways of seeing things that these technologies provide, in the end, other people are still the most important "content" in VR. **As more affordable, powerful, and easy-to-use stand-alone VR headsets have now started to become available, the possibilities for multi-user collaboration inside VR have also expanded tremendously.** VR is also increasingly being used for various training purposes. The benefits of VR are especially prominent in training use cases which are either too dangerous, expensive, or impossible to carry out in real life. However, the training scenarios also need to be sufficiently realistic to enable skill transfer from VR into real life.

AR on the other hand provides a novel and efficient way for users to tap into contextually relevant digital information from organizational information systems and other employees. Various remote support solutions were still the most popular AR apps in the interviewed companies because they are easier to adopt and create quicker returns on investments. AR also provides possibilities for visualizations of different products and design plans in the actual physical context (e.g., laying an architectural design plan in its intended physical location). However, in these use cases the interactivity and functionality are not as high as with VR due to limitations in information and graphical processing. On the other hand, **AR is likely to be the more ubiquitous solution when compared to VR as its use will likely diffuse into numerous use contexts** (often without people even consciously knowing that they are using AR, like is the case with AR filters in many social media apps).

As a crucial first step, management needs to acquaint themselves with the possibilities and limitations of AR and VR as top management support was identified to be critical for their adoption. They must also reserve time and allocate resources to explore how AR and VR could best be used in the SME context. Companies should also look into university and industry association cooperation to find out more about AR/VR use in industry. Companies will then have to evaluate whether they have the personnel to adopt AR/VR independently or if they have to order the solutions as complete turn-key packages from technology providers with implementation and training support included.

Before companies start using AR or VR, they must first ensure that their current software and information systems are ready and compatible with their desired AR/VR solution. **Some of the interviewed companies had tested AR/VR some years ago only to find out that the pipelines and workflows between their own systems and the new AR/VR solution were extremely time-consuming and impractical. However, during the last few years (2019-2020), a great deal has happened in this area to mitigate these issues. For example, in the AEC industry it is now possible to export digital building models into VR by the click of a button.** Companies should therefore review what new AR/VR functionalities have become available for the software that is currently in use in their companies.

Companies should also take a renewed look at the latest AR and VR hardware. The **newest stand-alone VR headsets provide superior ease-of-use, performance, and adaptability (by enabling PC tethering when needed) combined with a lower price when compared to many of the earlier headsets from a few years ago.** With regards to AR, **many smartphones and tablets provide intriguing and low-threshold possibilities for exploiting AR in business processes.** However, AR headsets also have their place, especially in use cases where freedom of movement is a requirement.

Most of the interviewed companies reported that their competitors had not yet started using AR or VR in a significant way. The interviewed companies who reported using these technologies themselves could therefore be seen as innovators. However, **it is likely that as more and more companies start figuring out the best ways to use AR and VR effectively, other companies will also start to feel the pressure to start using these technologies. Delving into these technologies ahead of time could create significant benefits for the companies in the future. Companies should therefore have a plan ready on AR and VR adoption in the coming years.** However, it is important to note that AR and VR are not applicable and useful for every company and business process. **It is therefore crucial for companies to identify critical business processes where the strengths of these technologies can be leveraged as much as possible in transforming how the company does business.** This will also secure a high enough ROI for AR and VR development efforts.

In summary, **we recommend that SME managers and employees follow the following 10-point action plan regarding AR/MR/VR adoption and use in their companies**:

1. Identify internal key resources to involve in the adoption of AR/MR/VR technologies
2. Familiarize your company on the possibilities and limitations of AR/MR/VR by signing up for relevant tutorials, webinars, or workshops
3. Identify critical business processes which could be transformed with AR/MR/VR and provide a high ROI for the investments. Also evaluate their impact on the company's overall business model.
4. Investigate whether your company's competitors have started using AR/MR/VR (either other SMEs or larger enterprises)
5. Discuss with your company's customers where they see most value in novel AR/MR/VR solutions and pilot test identified use cases
6. Examine whether your company's current software have recently introduced AR/MR/VR capabilities (e.g., streamlined BIM and CAD model exporting into AR/MR/VR) or what other available solutions could answer to the identified organizational needs
7. Identify relevant AR/MR/VR research and development projects and other sources of external support for piloting, testing, and further developing the identified solutions
8. Identify organizations within the local innovation ecosystem (universities, research & innovation centers, industry associations, technology providers) which can provide implementation support as well as opportunities for testing the newest AR/MR/VR hardware and software and gaining skills in using these technologies
9. Formulate an AR/MR/VR strategy for future adoption and use
10. Stay up to date on the latest AR/MR/VR developments

The VAM Realities project provides resources and support for executing this action plan. These resources can be found from the project website at https://vam-realities.eu/

At the project website, you can:

- Download and read our State-of-the-Art Report on AR/MR/VR technologies, software, and use cases to acquaint yourself with the possibilities and limitations of the currently available solutions.
- You can find both local and international AR/VR experts from our Expert Panel if you have any questions on specific topics here: https://vam-realities.eu/network-members/

- You can identify other relevant EU development projects related to AR/MR/VR on the website. You can find the list here: https://vam-realities.eu/related-projects/
- The VAM Realities project offers hands-on coaching and consulting services in the project partners' countries on how SMEs can integrate AR/MR/VR in their business processes. You can get your company involved in these pilots by contacting the project here: https://vam-realities.eu/#contact

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