WORKING PAPER

Digital age

Virtual and augmented reality: Implications of game-changing technologies in the services sector in Europe

Game-changing technologies: Transforming production and employment in Europe

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Related report: *Game-changing technologies: Transforming production and employment in Europe*

This working paper on virtual reality and augmented reality is one in a series of five presenting the findings of a study that examined the socioeconomic implications and applicability of game-changing technologies to the services sector in Europe. The other working papers in the series refer to the following technologies: advanced robotics, wearables, autonomous transport devices and blockchain.

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1. Introduction

Recent technological developments, underpinned by the growth of the internet, have implications – both positive and negative – for a range of sectors and stakeholders. However, while the potential implications are wide-ranging, they are not necessarily predictable, linear or deterministic. Developing a better understanding of the implications of the complex issues associated with technologies is therefore of critical importance for governments, policymakers, businesses, academia and citizens.

Incremental progress in technology could be expected to result in various economic and societal changes. However, technologies termed ‘disruptive’ or ‘game-changing’ are those transformative technological innovations with the potential to significantly reshape the way society does things, whether these be business and organisational practices or more generally associated with everyday life. Some technologies – such as artificial intelligence (AI) or improvements in battery storage – may develop as the result of incremental progress in a field and used in new, game-changing ways. Others – such as autonomous vehicles or blockchain – may provide opportunities for a fundamental reshaping of existing business and market practices and social organisation. While the impacts on markets and national economies are the most prominent examples, the changes go beyond the economic sphere. Significant shifts in business and consumption patterns may have wider socioeconomic implications as a result of the changing economic and labour patterns caused by the technology – such as the loss or displacement of some jobs, the creation of others, or the demand for new skills.

While the role of new technologies in reshaping the manufacturing sector has received noteworthy attention (Eurofound, 2018), there are also key implications for the services sector. As noted in the previous section, as described in the following section, the services sector is taking on an increasingly important role in the EU economy. Understanding the implications of game-changing technologies on the services sector will be essential for realising their benefits to society and the economy in Europe, as well as for minimising and preparing for the likely threats presented by the wider adoption of these technologies. The ‘game-changing’ context here refers to the potential of such technologies to critically influence or significantly change outcomes related to existing markets, market actors, established value chains, prevailing legislative, regulatory paradigms, economic thinking, and socio-political order, amongst others. [1] This working paper – one in a series of five working papers – presents the findings of a study that examined the socioeconomic implications and applicability of wearable devices to the services sector in Europe. This chapter presents the key objectives of the study, articulates the research approach adopted by the study team to meet the study objectives, and outlines the structure of the working paper.

1.1 Objectives of the study

The overarching objective of the study is to assess the potential applicability of the following five emerging and potentially ‘game-changing’ technology areas to the European services sector and the wider socioeconomic implications (Figure 1):

- **advanced robotics**;
- **autonomous transport devices**;
- **blockchain**;
- **virtual and augmented reality (VR/AR)**;

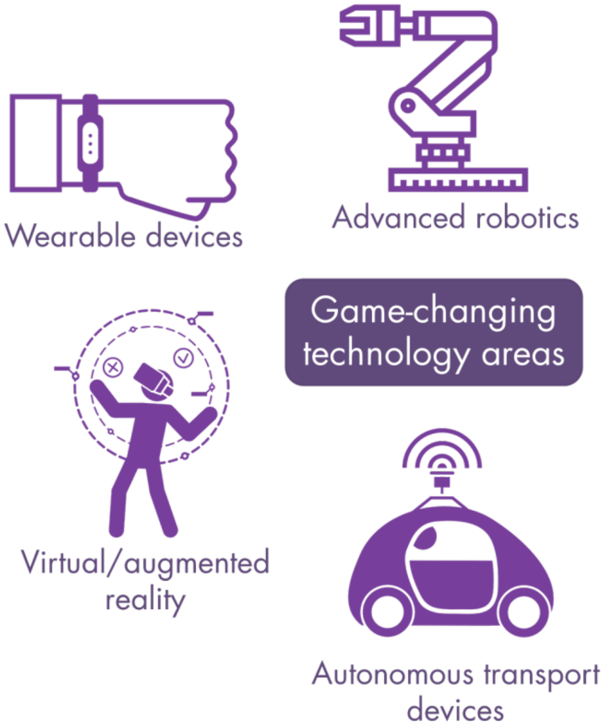
[1] Since there is no canonical definition of ‘game-changing’ technologies, as described here, game-changing technologies correlate to the concept of disruptive innovation which is often used to describe innovation that results in the creation of new markets and in some cases displaces existing market mechanisms including businesses, value networks, products and services. See Bower and Christensen (1995).

- **wearable devices.**

The study has the following four specific objectives:

- **Objective 1:** to assess the scope of applicability of the five technology areas to the services sector (and relevant subindustries where possible) in Europe;
- **Objective 2:** to examine the potential implications of these technology areas on productivity and output and on work organisation;
- **Objective 3:** to analyse the potential implications of the technology areas on employment and on skill levels;
- **Objective 4:** to assess the potential implications on working conditions (including implications for and interaction with individual and collective employment relations systems).

Figure 1: The five 'game-changing' technology areas covered by this study



Source: RAND Europe.

The five technology areas identified in the study are, to varying degrees, still in their infancy, in terms of (potential) widespread commercial applications and wider implications, yet they may have significant implications for the future of the services sector in Europe. The technology areas are listed in Table 1, along with brief high-level descriptions. The descriptions are not intended to be prescriptive or comprehensive; they serve as a general guide to the manner in which each technology area has been interpreted in the context of this study. In chapter 2, the working paper goes into more depth about the descriptions and characteristics of the specific technology area that is the focus of this working paper, namely, virtual and augmented reality

Table 1: Brief high-level descriptions of the five technology areas

Technology area	**Brief description**
Advanced robotics	Advanced robotics refers to the improvements in machine dexterity and the machine's ability to interact with its environment, as a result of which robots can be engaged in tasks that go beyond repetitive, discrete motions (Grant, 2012).
Autonomous transport devices	Autonomous transport devices are a field of technology that will allow vehicles to sense their environment and navigate without human input (Rohr et al, 2016).
Blockchain	Blockchain technology is one of the most well-known uses of distributed ledger[2] technologies (DLT), in which the 'ledger' comprises 'blocks' of transactions, and it is the technology that underlies a cryptocurrency such as Bitcoin (Deshpande et al, 2017).
Virtual/augmented reality (VR/AR)	VR is a computer-generated scenario that simulates a real-world experience (Steuer, 1992). AR combines real-world experience with computer-generated content (Azuma, 1997).
Wearable devices	'Wearables' are technology devices comprised of an ensemble of electronics, software and sensors, which are designed to be worn on the body (Billinghurst and Starner, 1999).

Sources: Azuma, 1997; Billinghurst and Starner, 1999; Deshpande et al, 2017; Grant, 2012; Rohr et al, 2012

The five technology areas cover a wide spectrum of potential uses and outcomes associated with the underlying technologies. These vary from more artefact-based use cases related to autonomous transport devices, wearable devices, and virtual/augmented reality, to blockchain, which could be considered an underlying (back-end) technology that provides the basis for the application of the technology in relation to specific uses. Furthermore, there are overlaps and commonalities between the technology areas themselves depending on the manner in which they are interpreted and characterised, for example, advanced robotics and autonomous transport devices (in the context of drones) or virtual/augmented reality and wearable devices (in the context of the way in which 'devices' are interpreted).

Recognising that the technology areas are in different stages of development and adoption, the study team adopted the following timelines (with 2018 as the baseline year) as a reference when discussing the trends and implications of the technologies:

- 'Near or immediate term' refers to the developments likely to take place within the next 1–3 years
- 'Medium term' refers to developments likely to take place within the next 4–7 years
- 'Long term' refers to developments likely to take place in 8 years and beyond

These timelines were informed by an initial scan of the available evidence and in consultation with expert advisors (see the annexes for more details).

[2] A distributed ledger is a digital ledger (a computer file used for recording and tracking transactions) that stores cryptographically authenticated information on a network of machines, whereby changes to the ledger are reflected simultaneously for all holders of the ledger.

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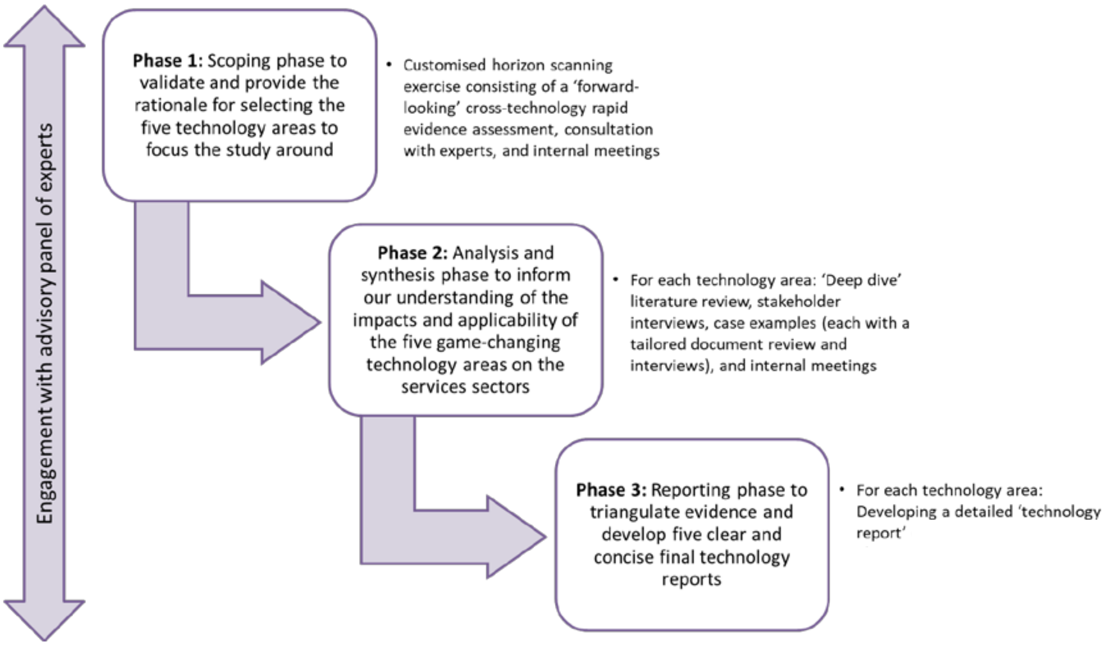
1.2 Research approach

The study was conducted from November 2017 to November 2018, and organised in three discrete but overlapping phases, as illustrated in Figure 2. Each of these phases is discussed in turn in the sections below.

The study team adopted a mixed-methods approach to design the study, relying on a set of carefully selected methodologies within each phase that were tailored to the study requirements. Throughout the study, the study team regularly consulted members of its advisory panel of experts (for example, to identify additional articles to review, to validate search terms, to suggest potential case examples and interviewee names, and to review the study team's analyses). Additional context on these phases is provided in the annex, which also discusses the limitations of the findings presented in the working paper.

Figure 2: Overview of the main study phases



Source: RAND Europe.

1.2.1 Phase 1: Scoping phase

The aim of this initial phase was to validate and provide the rationale for selecting the five technology areas to focus the study around, namely:

- advanced robotics;
- autonomous transport devices;
- blockchain;
- virtual and augmented reality;
- wearable devices.

Following discussions with Eurofound during the kick-off meeting, this 'validation exercise' was primarily aimed at assessing the extent to which these five technology areas remained relevant to the goals of this study. In addition, the validation exercise was aimed at ensuring that other emerging technology areas and existing technologies with transversal impact on the five technology areas were also considered. To implement the work in this phase of the study, the study team conducted a quick scan of the available evidence in the literature, as well as three scoping consultations with stakeholders that included cross-sector technology and socioeconomic experts.

1.2.2 Phase 2: Analysis and synthesis phase

The study team aimed to collate and assimilate evidence related to the scope and relevance of the application of the technology areas to services sectors in Europe, their wider socioeconomic implications (for example, for employment, skills and working conditions, and work organisation and productivity), and specific case examples to provide illustrative snapshots of their applicability and implications. To this purpose, the study team used a bottom-up, evidence-based approach.

For each of the technology areas, the authors carried out a comprehensive document review, web searches and conducted at least three key informant interviews with different stakeholders.

1.2.3 Phase 3: Reporting phase

Finally, the study team triangulated the findings with respect to each technology area in a way to address the main objectives of the study.

1.2.4 Conceptual framework

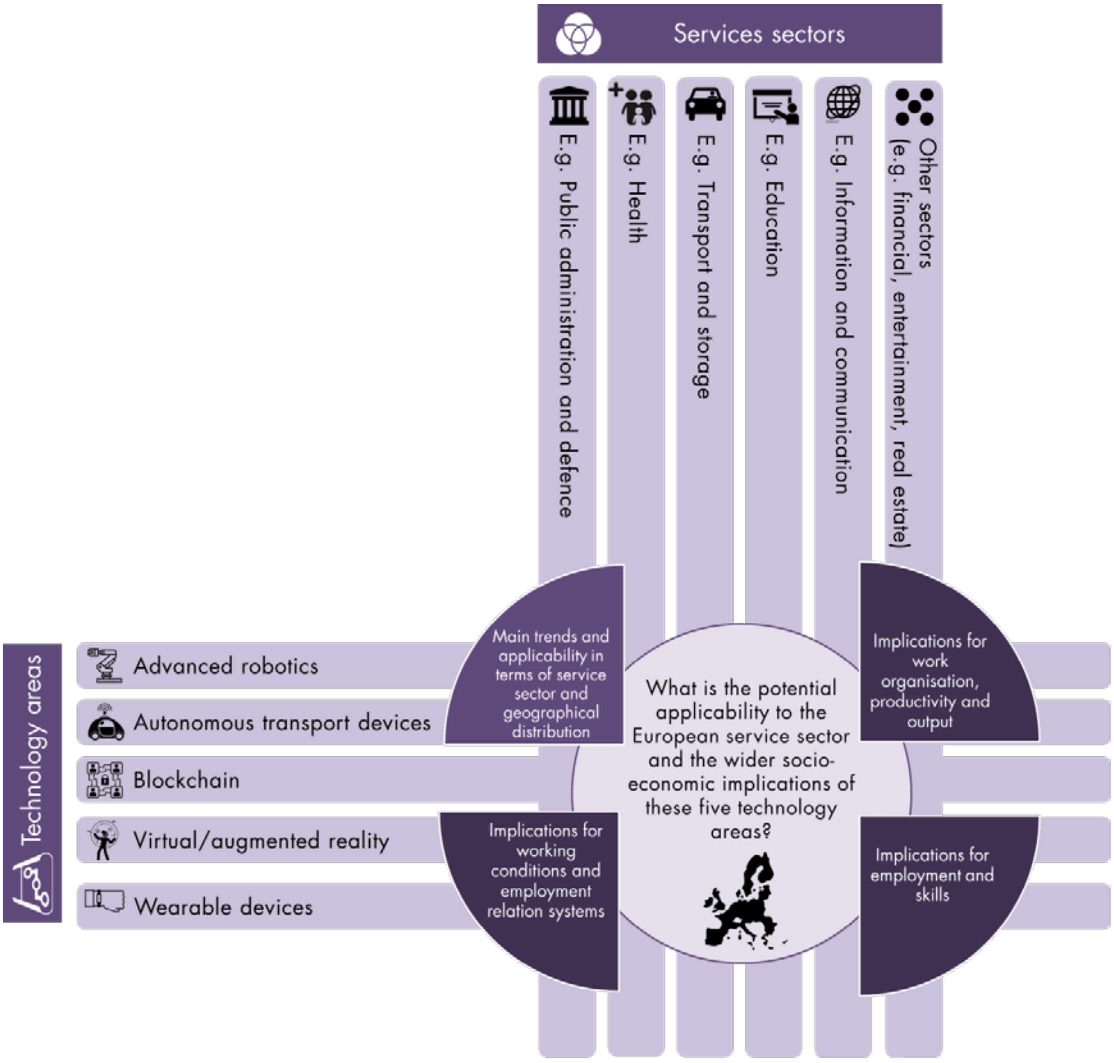
The conceptual framework for the study (Figure 3) provided an analytical instrument to assess the applicability and potential socioeconomic implications of the five selected technological areas to European services.

First, for each technology area, the study team acquired a general understanding of the important *trends* that are taking place; this enabled the team to portray a picture of the current state of play of each technology, as well as its general direction of travel in the near to medium term. In parallel, the study team also analysed some of the notable driving forces (that is, enablers) for and barriers to the development and adoption of the technology areas.

Second, the study team examined the (potential) *implications* of these technologies on several areas broadly linked to *employment* (for example, the changing nature of employment and tasks) and *working conditions* (for example, contractual arrangements and health and safety), skills (for example, levels and types), *work organisation* (for example, task allocation, work schedules) and *productivity*. (

The study team cross-analysed these factors in the context of different services sectors (and subindustries where possible) and geographical areas in Europe. Furthermore, where data are available, relevant snapshots on how the state of play varies in other parts of the world (for example, in the USA, China and Japan) have been provided. The study is largely qualitative in nature, but, where feasible, relevant quantitative data sources have been used to demonstrate the (potential) implications of the five technology areas.

Figure 3: Conceptual framework for the study



Source: RAND Europe

1.3 Structure of the working paper

The rest of this working paper is structured as follows:

- **Chapter 2** provides an in-depth discussion about the development and adoption of virtual and augmented reality across the services sector. It highlights the main trends that characterise the development of virtual and augmented reality, as well as the associated driving forces and barriers. Some examples of specific applications in the services sector are also discussed.
- **Chapter 3** presents a detailed analysis of the socioeconomic implications of virtual and augmented reality on several key areas of the services sector, such as employment, skills and working conditions, and work organisation and productivity.
- **Chapter 4** brings together the key findings of the study against the primary objectives and the main elements of the conceptual framework.
- **Chapter 5** includes three 'real-world' case examples that demonstrate the applicability and implications of virtual and augmented reality in the services sector in Europe

- The **annex** contains additional details about the research approach, including the search strategy for literature reviews and the interview protocol, and discusses limitations of the analysis presented in this working paper.

2. Development and adoption of VR/AR in European services

This section provides an overview of VR/AR as a technology area, in conjunction with the overall trends shaping the landscape, important drivers and barriers for the adoption of VR/AR, and potential applications of the technology. In the following discussion, the study prioritises published literature, with an emphasis on peer-reviewed articles, and draws additional material from interviews with external experts.

2.1 Overview of VR/AR technologies

Augmented reality (AR) and virtual reality (VR) are distinct technologies that could be conceptualised on a spectrum spanning reality to virtuality. According to an interviewed industry expert, there is no established and widely accepted definition of VR/AR, due to the rapid developments occurring in the VR/AR technology landscape. Broadly speaking, AR and VR can be defined as follows:

- **Virtual reality (VR)** is a computer-generated scenario that simulates a real-world experience (see Steuer, 1992, for further details). Lee (2012) provides a more simplified definition of VR as a technology that allows people to 'experience a computer-generated virtual environment'. Lee's (2012) definition thus recognises the potential of VR in immersive simulation of a real-world experience in the gaming industry and beyond.
- **Augmented reality (AR)** combines real-world experience with computer-generated content (see Azuma, 1997, for more details).When the recent advances in smartphone technology are considered, Lee's (2012) definition of AR as a technology 'that allows computer-generated virtual imagery information to be overlaid onto a live direct or indirect real-world environment' provides a useful context for the discussion in this working paper.

Both VR and AR involve interaction with virtual objects in real time; however, the element that differentiates the two technologies is the full immersion of the user in a VR environment; AR presents the user with virtual overlays on a real environment. Rather than be considered as two distinct technology outcomes, VR and AR should be seen as part of a spectrum of outcomes that span from reality to virtuality. An additional term used in conjunction with VR and AR is mixed reality (MR). Mixed reality is described as the 'merging of the real and virtual worlds, meaning that virtual objects are "anchored" to the real environment as opposed to "simply" overlaid' (European Commission, 2017). Thus, the level of immersion in MR may exceed that of AR, but it does not necessarily match the immersive experience of VR (European Commission, 2017). As stated above, mixed reality outcomes combine elements of real and virtual worlds, with augmented virtuality representing a step between overlay of real-world information in a virtual world (Doolin et al, 2013).

2.2 Trends shaping the VR/AR landscape

Box 1. Key trends in VR/AR landscape

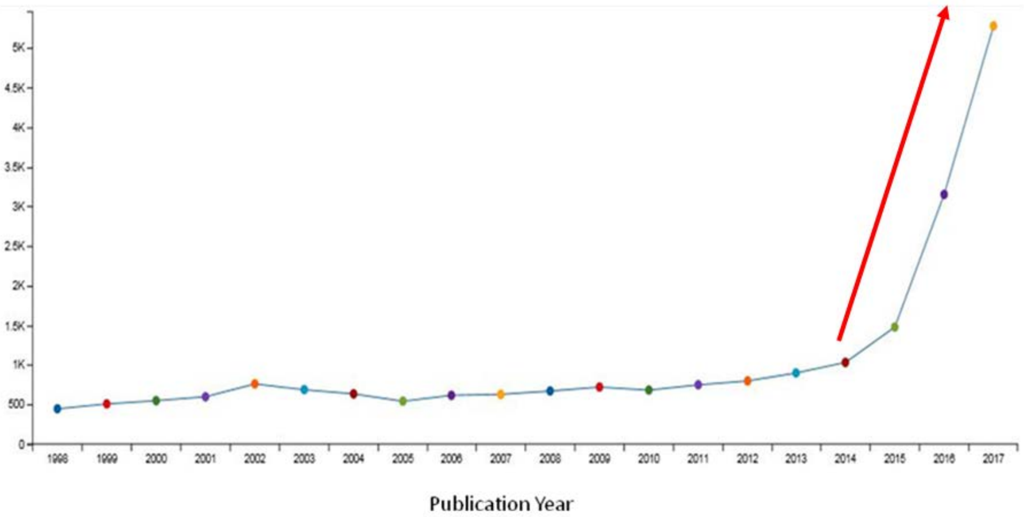
- The investment in VR/AR technology R&D has seen an upward trend since 2013.
- Europe is a growth market for development and diffusion of VR/AR technologies, with the UK and Germany being the leaders in the technology across the EU.

This section covers the regional and international trends in relation to VR/AR technologies. This analysis is informed by the patent applications and published research papers on VR/AR as a technology area. Given that the market for VR/AR is still developing and the technology has yet to see widespread market adoption, this discussion uses patent applications and published research as signals of interest and activity in relation to the technology.[3] This discussion is followed by specific trends related to the potential adoption of VR/AR technologies.

2.2.1 Interest and activity in VR/AR technologies

Figure 4 shows the number of patents[4] of virtual reality[5] since 1998. A marked increase in patent activity since 2014 is seen. Facebook's $2 (€ 1.7bn) billion acquisition of Oculus Rift, a company specialising in virtual reality, is seen as the tipping point for markets, with LeEco (China), Sony (Japan), Samsung (South Korea), Facebook and Microsoft (both USA) being identified as the organisations at the forefront of patent activity worldwide (Dhar, 2018).

Figure 4: Global trends for virtual reality-related patent applications, 1998-2017



Source: Based on Dhar, 2018. Reproduced with permission from Derwent, a Clarivate Analytics company. [6]

A similar trend of increased activity in relation to patents and publications[7] is seen since 2010 for augmented reality[8] technologies. Figure 5 draws on the findings from the Tools for Innovation Monitoring project (TIM, 2018). The underlying data for this analysis are based on patents, conference proceedings, book chapters, articles, and EU projects that either include an augmented reality component or are focussed on augmented reality as a core technology. In particular, a marked increase in the number of patents, conference proceedings, and articles in relation to augmented reality is seen since 2011.

[3] This discussion draws on the patent landscape reports available via the World Intellectual Property Organization's (WIPO) website and the data on patents and research publications published by Tools for Innovation Monitoring (TIM), created by the European Commission's Joint Research Centre (JRC). See the Annex for further discussion (including possible limitations of this approach).

[4] The key areas covered by the patents include virtual reality devices, simulation training, communication modules (including sensor, space information), and input operations (Dhar, 2018).

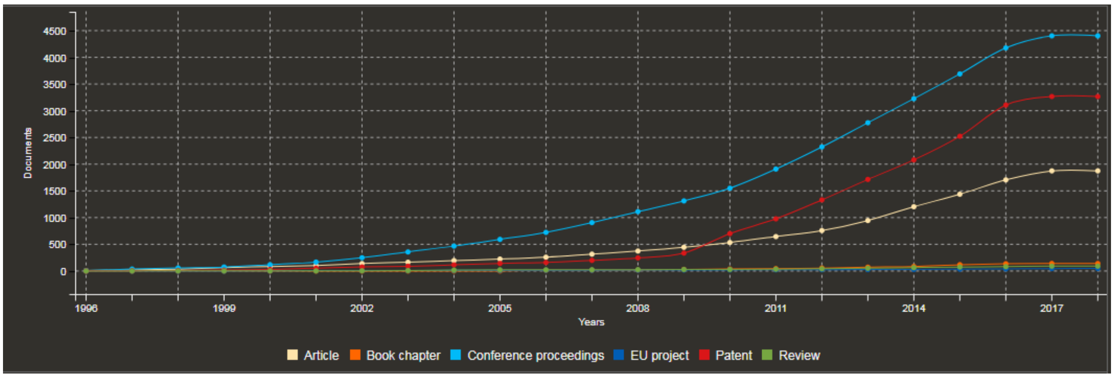
[5] This analysis is based on the LexInnova (2015) report, which describes virtual reality as a three dimensional, computer-generated environment which is immersive and can be explored and correlated by a person.

[6] The rationale behind the coloured dots is not fully explained in the source. The red arrow highlights increased activity on the filing of patents since 2014.

[7] The key areas covered by these outputs include augmented reality maintenance, head-up display, tangible interface guidelines, optical see-through, situation awareness, head-mounted display, sensor fusion, and human computation (TIM, 2018).

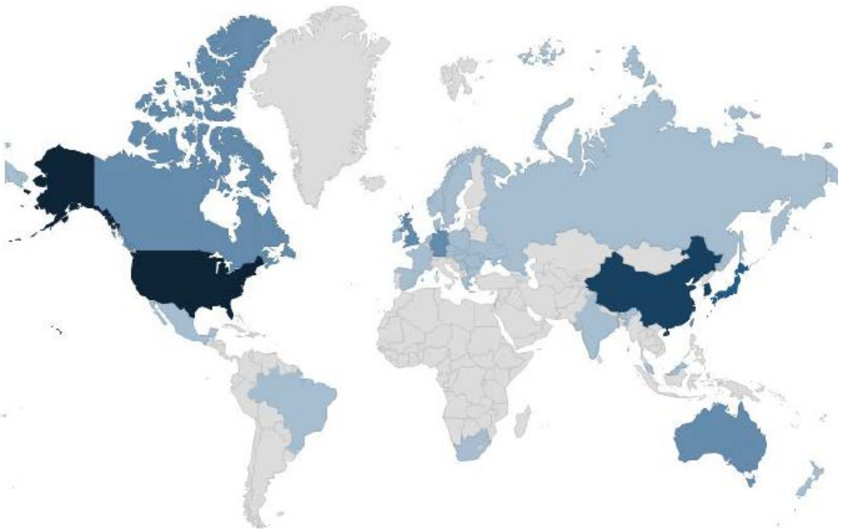
[8] This analysis is based on the Relecura (2017) and TIM (2018) reports, in which the term 'augmented reality' is referred to as any technology that enhances the perception of the user's surroundings by overlaying it with digital information.

Figure 5: Global trends for augmented reality-related outputs (including patents and research publications), 1996-2018



Source: Tools for Innovation Mapping, 2018. Original sourced with permission from the European Commission JRC, TIM project.

Figure 6: Geographical distribution of patents for virtual reality technology, 2015



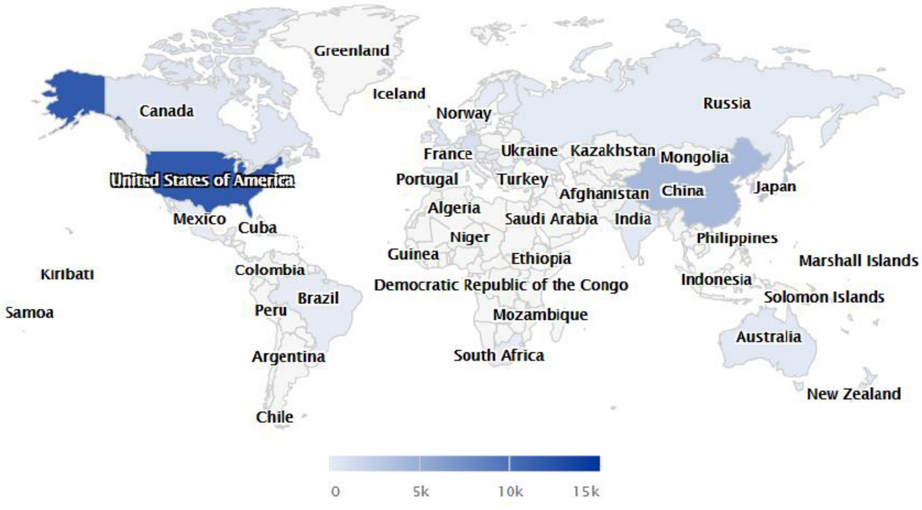
Source: LexInnova, 2015, and Dhar, 2018. Reproduced with permission from LexInnova Inc and Derwent, a Clarivate Analytics company. Darker shades of blue colour indicate more number of patents filed.

In terms of geographical coverage, the USA, China and South Korea account for approximately 75% of the total number of patent applications for VR between 1997 and 2015. Within the EU, the UK and Germany have the highest number of patents on virtual reality. The map in Figure 7 depicts this activity based on 2015 data, with darker shades of blue colour indicating higher number of total patents filed and recorded in a country.

Similarly, if the geographical coverage of patents[9] on augmented reality technology in 2017 is considered, the USA emerges as a leader, followed by China, as the countries with the highest number of patents filed. The map in Figure 7 depicts this activity based on 2017 data, with darker shades of blue colour indicating higher number of total patents filed and recorded in a country.

[9] The key areas covered by the patents include digital data processing, optical elements, image data processing, pictorial communication and data presentation (Relecura, 2017).

Figure 7: Geographical distribution of patents for augmented reality technology, 2017



Source: Relecura, 2017. Reproduced with permission from Relecura Inc. Darker shades of blue colour indicate more number of patents filed.

The above analysis shows that the patent activity in VR/AR as a technology area has been increasing across the world, with the USA, China and South Korea being the forerunners in terms of number of patents filed. Within the EU, the UK and Germany are the leaders in terms of number of patents filed.

2.2.2 Europe, a growth market for VR/AR technologies

Europe is considered to be a strong market for the development and diffusion of VR/AR technology, and stable growth in this market is expected in coming years, with the industry value projected at €15 billion to €34 billion by 2020 (Bezegová et al, 2017). France, the UK, Germany, the Netherlands, Sweden, Spain and Switzerland are some of the countries that exhibit high growth potential for VR/AR industries (Bezegová et al, 2017). Other countries signalling potential for high growth in VR/AR industries include the Czech Republic, Denmark, Estonia, Finland, Greece, Italy and Poland (Bezegová et al, 2017). Although these findings suggest that the adoption of VR/AR is growing in Europe, according to an interviewed industry expert, VR/AR adoption rates in Asia are higher in comparison to Europe. The same interviewee believes that this is due to Europe being traditionally more cautious about the adoption of new technology. However, the same interviewee also noted that once new technology (VR/AR in this case) gains an initial acceptance in Europe, its adoption may accelerate quickly.

Figure 8 depicts a snapshot of the overall VR/AR landscape in 2017, highlighting specific strengths of VR/AR developments in the USA, Europe and Asia. Academic research and the availability of research funding are cited as key strengths of the European market (Bezegová et al, 2017).

Figure 8: Snapshot of the global VR/AR landscape

Source: Bezegová et al, 2017. Reproduced with permission from Ecorys B.V. International

Box 2. Adoption trends for VR/AR (2018-2022)

Given the relatively early stage of adoption of VR/AR, definitive sectoral data on their deployment are not yet readily available. However, a recent report on the future of jobs by the World Economic Forum (WEF) provides some indicative data on potential adoption of wearable devices from 2018 to 2022. This is based on a survey of companies across the world done over a nine month period (November 2017 to July 2018) with a focus on large multinational companies and other companies which contribute significant revenue and employee size in a local context. The report used Occupational Information Network (O*NET) classifications of the sectors[10], which is retained in the next paragraph to ensure accurate representation of the findings.

Overall, 58% of the participating companies identified VR/AR (referred to as augmented and virtual reality in the survey and the report) as a technology they were likely to adopt between 2018 and 2022. When specific services sectors are considered, companies in the information and communication technologies (72%), automotive, aerospace, supply chain and transport (71%), and aviation, travel and tourism (68%) sectors reported a higher likelihood of adoption of VR/AR in comparison to the consumer (48%) and professional services (53%) sectors. 66% of the companies surveyed identified Eastern Europe as a market for the adoption of the technology from 2018 to 2022. For Western Europe, this figure was slightly higher at 69%. Among the European countries for which national-level data are provided in the report, the share of companies identifying France, Germany, United Kingdom, and Switzerland as potential markets for the adoption of wearable devices from 2018 to 2022 were 70%, 68%, 66%, and 72% respectively.

[10] Occupational Information Network (O*NET) is a database of occupational definitions of work in the USA available online at https://www.onetonline.org/. It was developed under the sponsorship of the US Department of Labor/Employment and Training Administration (USDOL/ETA) in the 1990s. As of 2018, it is maintained by the US National Center for O*NET Development. See Mariani (1999) and National Research Council (2009) for more details.

The report concludes that to achieve positive outcomes in relation to jobs in the wake of rapid technological change would require an emphasis on lifelong learning, reskilling, and upgrading of individuals' skills across a number of occupational categories. In particular, technology skills as well as non-cognitive soft skills would become more important. Governments would need to upgrade education policies targeted at increasing education and skills levels for all ages; leverage public and private sector partnerships to stimulate job creation; and revise existing tax revenue approaches and social welfare programmes in line with the new economic and business models of work. Industries would need to support upskilling of current workforce to become more technologically skilled; contribute to building a sufficiently skilled talent pool; and adapt to the increasing influence of the platform economy. The report argues that much as the workers would need to take ownership of their own lifelong learning, the governments and industries would need to support transition and reskilling at work in equal measure.

Sources: Mariani, 1999; National Research Council, 2009; World Economic Forum, 2018

2.3 Driving forces and barriers

Box 3. Summary of potential drivers and barriers

Potential drivers for the development and adoption of VR/AR

- Growth in the gaming and entertainment industry is a key catalyst for adoption of VR/AR.
- The reduced cost of software and hardware combined has accelerated the growth of VR/AR.
- The growth in smartphone devices, increased capability of smartphone hardware and increased availability of similar mobile devices has increased the accessibility and reach of VR/AR technologies.
- Increased availability of digital content through online distribution platforms has made adoption and spread of VR/AR technologies more viable.

Potential barriers to the development and adoption of VR/AR

- The potentially high cost of VR/AR system infrastructure can be a disincentive to the adoption of VR/AR.
- Poor connectivity to the web could limit access to VR/AR systems.
- Health concerns, such as simulator sickness, dizziness and/or headaches, could deter adoption of VR/AR.
- Perceived usability challenges may impede the adoption of VR/AR.
- Ethical and privacy issues could hinder the adoption of VR/AR.

2.3.1 Potential drivers of the development and adoption of VR/AR technologies

Growth in the gaming and entertainment industry

The gaming and entertainment industry is the top application area for VR/AR as of 2017/2018, and a large proportion of VR/AR development activity is occurring in this industry (Bezegová et al, 2017). Video games have been the focus market for the VR content industry (Muikku and Kalli, 2017), and some projections highlight the video games industry to be the highest revenue-generating market for VR/AR (Goldman Sachs, 2016). The use of VR/AR in the gaming and entertainment industry has been mostly focused on consumers.

Although it has seen specific uses in sectors such as defence,[11] there is limited evidence of its widespread use in workplaces. As a result, the wider implications of VR/AR for working conditions, employment and productivity beyond the current niche uses are not yet known.

Reduced cost of underpinning software and hardware

The cost of VR/AR hardware and software is decreasing, which could contribute to increased prevalence of VR/AR in everyday work life (Cognizant, 2018; Leovaridis and Bahna, 2017). As of 2018, more than 150 companies worldwide in a range of industries, including 52 of the Fortune 500, have either tested or deployed VR/AR solutions (Cognizant, 2018). According to an interviewed European researcher, VR/AR is becoming more accessible with the advent of more compact and mobile devices.

According to an interview with an European academic expert, the growing use of technologies which are synergistic with VR/AR, such as wearable technology, cloud computing, and storage and advancements in battery life and software content could also accelerate the growth of VR/AR deployment in workplace contexts (see also World Economic Forum, 2017).

Increased availability and use of mobile devices

According to an interviewed European academic expert, mobile devices that make use of VR/AR are becoming easier to use, and their components, such as gyroscopes, accelerometers, GPS, ambient light sensors, digital compasses and more, are becoming more accurate. A number of devices on the market or in development combine VR/AR with wearable technology, so developments in wearable technology could enhance the utility of VR/AR (Doolin et al, 2013). This was reflected as early as 2013 in such products as Google's Project Glass and Microsoft's Project Fortaleza (see Table 2 for more recent examples), which integrate VR/AR and wearables to create new solutions. The growth of sensor technology is also considered to be complementary with VR/AR due to sensor technology's motion-sensing functionalities (Williams-Bell et al, 2015), which augment such applications as virtual-reality training.

Increased availability and diversity of VR/AR digital content

In addition to improvements in the component hardware systems of devices utilising VR/AR, an interviewed European academic expert noted that there is also access to increased digitised content that can be shared, explored, used and reused.

Some examples of VR and AR solutions in the market as of the second half of 2018 are included below. The following table provides a typology of VR/AR devices on the basis of software, hardware and costs of production.

Table 2: Examples of VR/AR products on the market

	Device type	**Device type description**	**Products**
VR	Smartphone VR headsets	These devices are the low-cost alternative to VR headsets and typically connect a head-mounted display to the user's	Samsung Gear VR; Google Daydream View; Google Cardboard; Merge VR Goggles; Xiaomi Mi VR Play

[11] For example, Lockheed Martin has been running Combined Arms Tactical Trainer for the UK Ministry of Defence since 2001. Combined Arms Tactical Trainer is a synthetic training facility using an immersive, computer-generated environment; it has been used to train more than 100,000 service members of the British Army on a virtual battlefield (Army Technology, 2015).

	Device type	Device type description	Products
		smartphone.	
	Stand-alone VR headsets	These devices are more sophisticated than smartphone VR headsets and typically have powerful consoles.	HTC Vive; HTC Vive Pro; Oculus Rift; Oculus Go
AR	Hand-held AR devices	These devices are typically connected to smartphones or tablets. There are numerous AR apps available, and some organisations are developing custom apps for the needs of their workforce.	AccuVein; ARnatomy; BMW i Visualiser
	Wearable AR devices	These devices combine wearables, such as glasses, with AR overlays.	Google Glass Enterprise; Vuzix; Meta; Takram

Source: RAND Europe analysis.

2.3.2 Potential barriers to the development and adoption of VR/AR technologies

High cost of investment in system infrastructure

The cost of initiating and maintaining a VR/AR system infrastructure (including devices, network connectivity and other physical infrastructure) can disincentivise the use of VR/AR technologies (Merchant et al, 2014). This barrier was also identified by two interviewees[12] as part of the discussion on VR/AR. The viability of VR/AR systems depends upon the organisation's data and technology infrastructure (Doolin et al, 2013). However, according to an interviewed European researcher, to produce a VR simulation that is impactful would require the work of an interdisciplinary team that could include social psychologists, artists, modellers, film makers, developers, technologists and more, which could require a considerable amount of financial investment. Additionally, the same interviewee highlighted that the devices need to be designed for specific audiences and to be user-centric, but sometimes these audiences are yet too small to fund the development of the device or generate a profit. There are also questions regarding who ought to be paying for the establishment of the infrastructure, particularly in relation to the use of VR/AR systems for public services and as an expense in cases where the benefits of the technology are insufficiently proven (Cowper and Buerger, 2003). Extensive technical support from specialists is typically required to set up and maintain the systems, and this can significantly add to the cost of adoption of VR/AR technologies (Tsang and Man, 2013; Leovaridis and Bahna, 2017).

One barrier to the adoption of VR/AR is the concerns regarding the health effects associated with VR/AR systems, such as simulator sickness, dizziness, headache, nausea or eye-strain (Tsang and Man, 2013). These effects are usually short term and subside when VR/AR technologies are not in use. Since the technology has mostly been tested on Caucasian males

[12] Based on separate interviews with an European research and an European academic expert

aged 20-30, the implications of these side effects on other segments of population, such as older men, women and people from non-Caucasian backgrounds, is yet to be understood (Munafo et al, 2017). In addition, the long-term implications of the use of these technologies and the extent to which these can aid or affect productivity in a workplace are not known. This can potentially deter organisations from adopting VR/AR systems.

Ease of use and user competence

The effective deployment of the technology also depends upon the system's ease-of-use and users' competence and affinity for mobile devices (Tsang and Man, 2013). This competence will require investment in employee training on VR/AR systems (Doolin et al, 2013). The usability of the headset or the glitches in the software that impede the smoothness of the virtual experience can constrain the technology from reaching a wider audience (Bezegová et al, 2017). However, as noted by one interviewed European academic expert, if VR/AR is connected to a smartphone, then the usability, security and functionalities of the smartphone can significantly affect the usability of the entire system.

Poor connectivity to the web

If VR/AR is to be deployed in service sectors more widely, there may be a need for an ecosystem that allows users to connect and collaborate securely around the clock (Cognizant, 2016). One interviewed European academic expert suggested that, given the increased importance of streaming content, low-speed internet or bandwidth-poor connectivity to Wi-Fi and 4G or 5G can also act as hindrances to the adoption of the technology. In this context, the advent of 5G wireless connectivity and networks could be a crucial enabler for the uptake of VR/AR technologies and is likely to be critical to the adoption of the technologies in the long term (Campos, 2018; Newman, 2018; Qualcomm Technologies Inc, 2018). However, in the interim period leading up to the deployment of 5G networks, poor connectivity to the web and limited access to streaming content could limit the access to VR/AR systems.

Ethical and privacy issues

Public distrust of the technology and the ethical, legal and data privacy issues it raises can also constrain the adoption of VR/AR. The invasion of users' privacy and access of personal data remains a challenge (Jung and Han, 2014). Moreover, according to an interviewed industry expert, devices, such as smart glasses, that combine AR and wearables and that may have functionalities that record the user's daily movements and interactions, could generate public discomfort.

2.4 Potential applications in the services sector

The literature reviewed suggests a range of possible applications in such service sectors as education; retail and online trading; project design, engineering and prototyping; architecture and urban planning; police and security; fire services and emergency management; and logistics and healthcare services. Some common applications that cover a range of service sectors include VR/AR-facilitated training systems, marketing and public engagement, instructional tools, and 3D visualisation and simulation.

2.4.1 Education and training

According to an interview with an European researcher, educational services in schools, higher education and businesses could benefit from VR/AR by providing realistic, contextual, on-site learning experiences in classroom-based settings to test knowledge and problem-solving skills (see also Lee, 2012). In businesses, VR/AR systems could be adopted for services and other industrial training (Lee, 2012; Dini and Mura, 2015), although it is more likely that large companies with higher numbers of workers will make the investment in VR/AR than it is for smaller companies, due to the cost of purchasing the devices and setting up the supporting infrastructure for these devices. Driving school instructors could also use devices using mixed reality to expose students to simulated driving scenarios that may be too complex or dangerous to experience in real life (Blissing et al, 2013). Similarly, VR simulations of training in fire services could reduce risks of exposure to hazards that could cause injuries and deliver a more cost-effective method of training (Williams-Bell et al, 2015).

A possible advantage of conducting training in simulated VR environments is that it allows employers to create training programmes without the constraints of real-world environments, such as cost, machine availability or safety concerns (Gavish et al, 2015).

AR-facilitated training programmes typically use AR for memory cues that are superimposed on real environments in situ. Students and workers can be guided through tasks using step-by-step AR-supported tools that can help to improve productivity with limited requirement for prior training (Abraham and Annunziata, 2017). Visual checklists and on-demand instructions along the users' field of vision on the job can also augment experiential learning processes and reduce the risk of error, particularly during times of fatigue or extreme stress (Doolin et al, 2013). Some examples are presented below.

- Technicians wiring wind turbines at General Electric are testing the use of an AR headset that guides their work through line-of-sight instructions during the job (Abraham and Annunziata, 2017).
- BMW's Munich-based engineers designed a pair of AR glasses that show users and mechanics step-by-step instructions on how to fix an engine, simply by looking at it. These glasses can help those with no previous mechanical experience (Boeriu, 2014).
- VR is also being used extensively for training police and military services, such as the VR used in the Dutch National Police's Police Academy (Politieacademie, n.d.), the Virtual Battlespace software VBS3 used by more than 30 NATO members (Army Technology, 2014), the Combined Arms Tactical Trainer system for immersive virtual battlefield experience used by the British Army since 2001 (Army Technology, 2015), and the Automated Serious Game Generator for Mixed Reality Training used by Greece's Piraeus Port Authority (2018). VR-based immersive experiences are also being used in the training of pilots to reduce costs and to simulate a broader range of scenarios as part of training, in addition to the existing flight simulation systems in the aviation industry (Ellis, 2018).[13]
- VR could be used to incorporate tolerance and empathy into training programmes, according to an interviewed European researcher VR could be utilised to allow employees to understand colleagues' jobs, as well as the work of those in other industries (Cohen and Gretczko, 2017). This could increase employee engagement by aiding workers to interact with their teammates in better ways, which is conducive to the development of more interconnected and effective teams (Cohen and Gretczko, 2017).
- VR could also be used to support job training for individuals from disadvantaged groups, for example, those with the psychiatric disabilities bipolar disorder or

[13] Although flight simulators used to train commercial pilots have used a form of virtual reality through full motion simulators (also called full flight simulators) for more than 80 years, these are not considered fully immersive VR environments (Ellis, 2018). The flight simulators currently in use are created by chopping off the front part of an airplane and mounting it on a platform that can be used to move the physical cockpit to six degrees (Ellis, 2018). Video displays are installed in front of this cockpit to give pilots a 'virtual' view of the landscape or runway (Ellis, 2018). Although immersive virtual reality applications are being increasingly used in the aviation industry, some experts argue that the physical, tactile experience of the full motion simulators offers a better experience of the real cockpit (Cox, 2018; Adams, 2018).

schizophrenia (Smith et al, 2014). VR training ahead of a potentially anxiety-triggering interview could allow a trainee with special needs to practice in an environment under the trainee's control and allow the trainee to repeatedly practice in a realistic, context-aware, simulated setting without penalty (Smith et al, 2014).

2.4.2 Marketing

VR/AR's involvement in marketing and advocacy intersects across the different device types and applications listed in Table 2. VR/AR could more effectively capture the public attention through targeted messages (Bule and Peer, 2014).

Retail and online trading can be augmented by VR/AR by allowing brands to create new methods of in-store experiences and services that integrate customers' personalised, individual preferences and therefore engage customers more effectively (Altarteer et al, 2016). AR could blend reality and digital interactions, which could support some types of face-to-face services from a distance (Eurofound, 2018). On interviewed industry expert said that VR/AR solutions can enhance the 'storytelling' aspect of sales, allowing the customer to imagine the full potential of a product. In online shopping, potential consumers typically do not have the chance to try on purchases, but they can do so through virtual try-and-buy systems. Topshop has experimented with virtual dressing rooms (Sterling, 2011). Amazon has developed a mirror that allows users to try on virtual clothes (Alvarez, 2017). AR also has the potential to alter consumers' shopping habits and change existing practices in the retail sector by persuading consumers to purchase products and services (Jung and Han, 2014) through visual cues and timely nudges.

In the tourism sector, AR marketing campaigns are perceived by businesses to be a tool for low-cost marketing (Jung and Han, 2014). In museums and other cultural heritage sites, VR/AR is being used to market to audiences and reduce costs. In this sector, one of the interviewed European academic expert noted that items that are very fragile, very expensive, or too large or small to be placed in the exhibition can be displayed through VR/AR devices. This allows the organisation to display the item without exposing it to possible harm and associated costs if it is damaged. Additionally, it allows museums and cultural heritage sites to expand their offer in a cost-efficient manner. According to the same interviewee, novel methods of displaying or showcasing items could make exhibitions more attractive to audiences. The distinction between AR-facilitated tour guides and displays and the simple, two-dimensional views offered by television screens is the novelty of the perspective offered to the audience, which, because it mixes the audience's view with reality, is more immersive.

Some not-for-profit organisations are using VR to disseminate messages more effectively. Some campaigns seek to generate empathy or seek to help potential donors visualise the impact of their donations (Cohen and Gretczko, 2017). The United Nations is using VR as an educational and advocacy tool to engage the public on issues it is tackling for fundraising, high-level advocacy and educational programmes (United Nations, 2017).

Table 3 identifies some examples of uses of AR technologies in relation to marketing services. Given that some of these solutions are in the early stages of deployment, the impacts are not yet fully realised.

Table 3: Examples of VR/AR marketing solutions

Example	Sector(s)	Description	Potential impacts
Magic Mirror (Bule and Peer, 2014)	Retail; marketing	This solution allows users to try on footwear virtually through AR, allowing the users to visualise their reflection with a virtual model of the shoes.	• Magic Mirror could positively influence consumers to purchase goods, which could translate to increased revenue and profits. • Magic Mirror could reduce transportation costs for retail firms by reducing return rates, since potential buyers will be able to virtually try on products before making a purchase.
Cisco's AR commercial (Bule and Peer, 2014)	Retail; marketing	This solution allows users to try on clothes before a 'magic screen'.	This AR solution could influence customers to purchase products, thereby generating sales.
McDonalds' Pokemon Go 'pokestops' (Dacko, 2017)	Hospitality; marketing	McDonalds restaurants have adopted a marketing strategy that advertises the presence of so-called Pokestops. These allow users to catch Pokemon on the popular Pokemon Go AR app, which has been downloaded by tens of millions of users.	This marketing strategy leverages the popularity of the Pokemon Go app to draw consumers and is aimed at increased patronage.
Thomas Cook VR Fantasy Flight (VISUALISE, 2018)	Tourism; marketing	The travel agency Thomas Cook collaborated with Samsung and VR filmmakers Visualise to create 360° VR films for its stores in Belgium, Germany and the UK.	This immersive VR experience is geared to allow the potential customer to envisage holiday experiences and to influence customers to book the trip, thus contributing to conversion rates.
Lufthansa FlyingLab (FlyingLab, 2018)	Tourism; air transport; marketing	The airline Lufthansa began FlyingLab flights in 2016, which allow passengers to test its products and services on board through VR.	Lufthansa aims to use VR to promote the benefits of premium upgrades and other services to aid in increasing revenue.

Sources: Bule and Peer, 2014; Dacko, 2017; VISUALISE, 2018; and FlyingLab, 2018.

2.4.3 Design, engineering, prototyping and testing

In project design, engineering and prototyping, VR could include remote collaboration through VR environments or could allow engineers and designers to design products in the environment in which the product will be used (Kiryakova et al, 2017). For example, VR environments could facilitate virtual prototyping of vehicles through the remote collaboration of various teams in real time. One example of this is the Ford Vehicle Immersion Environment, which is a virtual reality laboratory that allows designers and engineers to collaborate inside VR environments, side by side and on the same product (Gaudiosi, 2015). Companies such as Siemens have developed VR-facilitated 'virtual twins' of production processes that essentially simulate the behaviour of products in a virtual setting to support product testing and maintenance processes (Eurofound, 2017). These examples suggest that the 'servitisation' of manufacturing - which is the transformation of manufacturers from product makers to services providers - is likely to be facilitated by AR/VR applications.[14]

Moreover, engineering processes typically involve evaluations of safety systems, and VR could be used to simulate safety systems in transportation. VR could combine the visual input of the driver with digitally generated objects in VR simulations that make it possible to perform tests that are impossible to carry out in real environments due to the risk exposure of the driver or the public (Blissing et al, 2013).

In addition to prototyping tangible products, VR visualisations could also be used for service prototyping (Oh et al, 2013). This involves the testing of new services that require interaction of the user with the prototype of the service. For example, the Fraunhofer Institute has developed ServLab, which is a VR service laboratory used to test a client's real-world service in a VR environment (Hofmann et al, 2012). VR environments can be used to test service execution, scene management and event management (Oh et al, 2013).

In architecture and urban planning, VR/AR is typically used for planning and designing elements of the design before they are in existence (Portman et al, 2015). Virtual design studios can facilitate co-design processes, such as reported in one study by Dorta et al (2011), where the authors describe being virtually - and effectively - 'teleported' into each other's design plan. One pilot of a framework sought to increase public engagement in urban planning through AR. The Augmented Reality for Public Engagement (PEAR) project trialled a framework using an AR mobile app (PEAR 4 VXO) in the municipality of Växjö, in Sweden (Alissandrakis and Reski, 2017). The app invited the public to vote on the future development of the Ringsberg/Kristinebergs area in Växjö based on the visualisation of the proposed urban planning changes, through an AR mobile application (Alissandrakis and Reski, 2017).

2.4.4 Security monitoring, operations planning, investigation, and remote and mobile teamwork

In such government services as police operations or border inspections, VR/AR has applications for operations planning and intelligence gathering and can improve situational awareness to facilitate collaboration between mobile and dispersed teams (Lukosch et al, 2015; Cowper et al, 2004; Datcu et al, 2015a, 2015b). For example, VR/AR solutions could help provide facial recognition, voice-prints, and biometric recognition data for instant recognition within a given area. VR/AR solutions could also provide law enforcement professionals with real-time intelligence; three-dimensional maps; information on chemical, biological and explosive dangers; operator data on patrol cars; and regional traffic

[14] Further explanation of the trend towards servitisation is covered in Annex A. See also Baines et al (2009) and Fontagné and Harrison (2017) for more details.

information to allow them to improve situational awareness and respond to problems more quickly (Lukosch et al, 2015). This could allow for more efficient and agile responses in dangerous situations and improved team coordination and supervision (Lukosch et al, 2015). AR video, audio and sensing capabilities can also be used to visualise blood patters, stains and other forensic data at crime scenes for forensic analysis (Cowper et al, 2004).

Finally, AR equipped socio-meters, which seek to quantify and analyse social interaction patterns, could detect potential threat behaviour and contribute to ambient security, for example in airports (Doolin et al, 2013). At security checkpoints, these applications could potentially reduce the risk of error (Doolin et al, 2013). Security threats could be recognised more quickly and with more accuracy.

Emergency management and search and rescue operations in the fire and other emergency services sectors can be supported by VR/AR through communications (Vasell et al, 2016). VR/AR-supported 3D mapping of the environment and virtual compasses that show emergency service personnel target locations can also be a useful tool for emergency service workers (Deloitte, 2013). In a mass casualty disaster scene, medical personnel can experience challenges in delivering care without the necessary communication infrastructure and collaborative technologies, due to the need to deliver care outside a hospital infrastructure (Vasell et al, 2016). VR-facilitated systems can be used to collaborate between hospital staff and remotely situated emergency medical service personnel (Vasell et al, 2016). For example, VR could help a medical director or incident commander see and understand the situation in a disaster scene and coordinate effectively, as well as delegate triage responsibility in an effective manner (Vasell et al, 2016). VR simulations can also support firefighting and evacuation training in a safe, ethical and cost-effective manner, in which fire fighters and other emergency service operators can practice in dynamic scenarios that allow trainees to repeat exercises and correct mistakes, as well as practice team coordination and other task-level skills (Williams-Bell et al, 2015).

2.4.5 Assisted procedures, surgery planning, telemedicine and rehabilitation

AR can support healthcare services by allowing health personnel to diagnose or assess patients' progress without making an incision (Cognizant, 2018). For example, one study developed an AR mobile application that uses the microphone in the user's mobile device to analyse heart sounds and detect irregularities (Hemanth et al, 2018). AR-supported devices can also support surgery planning procedures, for example in tumour resection interventions (Abhari et al, 2014). Furthermore, AR can better facilitate teleworking and remote collaboration involving doctors and other specialists in different locations by providing real-time visual feedback (Andersen et al, 2017). Moreover, AR can introduce innovative ways of supporting medical education (Cognizant, 2018). For example, a feasibility study demonstrated an AR-based coronary artery diagnosis and preoperative planning system called ARS-CADPT, which models the coronary artery system and accurately reconstructs the area where the surgery is planned (Li et al, 2017). This AR system is envisaged to help doctors carry out surgical planning in a more intuitive way (Li et al, 2017).

Personnel who experience constant exposure to distressing images and experiences, such as war and terrorist attacks, experience higher risks of posttraumatic stress disorder (PTSD). Applications for VR are being explored to deliver exposure therapy for PTSD and other, related psychosocial conditions (Cuckor et al, 2015; Loucks et al, 2018).

2.4.6 Tracking and troubleshooting in logistics

Logistics can be augmented by VR/AR tracking systems - for example, by allowing warehouse workers to safely and quickly identify the exact location of items and remove them for packing and shipping (Cognizant, 2018). VR could also allow employees to troubleshoot problems and track products that travel along assembly lines with increased efficiency when compared to existing, non-immersive approaches (Cohen and Gretczko, 2017).

3. Potential socioeconomic implications of VR/AR

Given the early stages of deployment of VR/AR technologies, the publicly available evidence on impacts is emergent and limited. In a number of cases, the evidence outlines potential rather than realised impacts. As a result, the implications identified here are initial indications of developing trends that may change once VR/AR technologies gain wider acceptance and deployment.

A number of available VR/AR solutions are pilot studies and projects that have sought to demonstrate the viability of VR/AR solutions to realise potential advantages of introducing these technologies in the workplace. Because many products on the market are combined with wearables, some applications and impacts are a result of the combined functionalities of the two technology areas. Where this is the case, the analysis distinguishes between impacts that are more attributable to the VR/AR function of a device and those that are likely caused by the device being wearable.

3.1 Implications for productivity and outputs

Box 4. Summary of potential implications for productivity and outputs

- VR/AR could contribute to improved employee performance, particularly in the logistics sector.
- VR/AR could increase procedural effectiveness and produce more efficient distribution of resources in healthcare services and in the retail sector.

3.1.1 Employee performance

VR/AR can create opportunities for the optimisation and enhancement of processes and problem solving through the gamification (that is, application of game playing elements to non-gaming activities) of work (Leovaridis and Bahna, 2017). In logistics firms, GE Logistics has reported that warehouse order fulfilment tasks were completed 46% faster through AR, as workers did not have to refer to workstations, but instead accessed inventory information through smart glasses (Cognizant, 2018). One interviewed industry expert noted that the use of VR/AR in DHL has been reported to deliver productivity gains of 25%, with overall gains for the company valued at 10%. Visual ‘push’ notifications, reminders and checklists can aid in memory recall and reduce errors – particularly for repetitive, mundane, but essential tasks (Doolin et al, 2013) - which can improve the efficiency of work processes (see Box 5). Another example is General Electric (GE), where a technician’s performance was reported by the company to have improved by 34% through the use of an AR headset (Abraham and Annunziata, 2017).

Box 5. Google Glass Enterprise Edition

One example of a relatively well-known so-called assisted reality solution that leverages the combined benefits of AR and wearable devices for the workplace is Google’s Glass Enterprise Edition (Glass EE). Google Glass was evolved into the Glass EE, which is specifically developed as a workplace tool to help large business organisations make productivity and efficiency gains, reduce costs and improve conditions for workers.

The solution is built like a pair of glasses, with a choice of options. One option uses AR to overlay digital information on top of the real world on the frames, and the other allows workers to shift between virtual and actual reality (Levy, 2017). These smart glasses are a lighter, cheaper and portable version of typical AR headsets. The Glass EE can also be equipped with customised software for the specific needs of enterprises.

Glass EE could allow the user to gain efficiencies and productivity by overlaying instructions and real-time guidance on the screen and reducing inefficiencies associated with constant back and forth to computers and paper material. In the healthcare sector, in can be used to dictate notes as practitioners provide services, reducing the time required to type up patient notes and conduct other administrative work. It is also envisaged to reduce dependency on other workers and managers, eliminate distracting and inefficient physical manuals, improve accuracy of calculations, speed up access to help through livestreams of tasks for feedback and generate time and cost savings (Klara, 2017).

The Glass EE is intended to be a departure from the first generation of the Google Glass, which was made for consumer consumption and critiqued for the prevalence of technical challenges and the lack of clarity regarding its functionality. In 2014, Google initiated the Glass at Work programme for the original Google Glass, which inspired the development of Glass EE (Levy, 2017). Other improvements include longer battery life for long shifts and faster processing units to further support networking and collaboration at work.

Although primarily envisaged to aid the manufacturing industry, the Glass EE holds relevance for the design and engineering sectors, which also contributed to prototyping processes. Some sources posit that applications for other sectors, such as healthcare services, logistics and field service, are also beginning to experiment with Glass EE and that the previous Google Glass model had already been used by luxury fashion brands, such as Diane von Furstenberg, and airlines, such as Virgin Atlantic Airlines (Levy, 2017). Firms that have begun experimenting with Glass EE include General Electric, Boeing, DHL, Volkswagen, the testing and certification organisation NSF International, Dignity Health and Sutter Health.

Comparable competitors in the European market include Proceedix in Belgium and Microsoft's HoloLens and Project Fortaleza.

3.1.2 Work procedures and resource allocation

In the health sector, a number of feasibility studies have demonstrated the utility of employing VR/AR devices to assist medical personnel in surgical procedures (Frajhof et al, 2018; Borgmann et al, 2017; Gans et al, 2015). For example, one feasibility study, by Borgmann et al (2017), explored how effective smart glasses could be in employing AR technology for urological surgery. The feasibility study found no intrinsic or extrinsic obstacles to the employment of AR for urological surgery (Borgmann et al, 2017). Around 43% of surgeons who participated in the study rated the overall usefulness of AR-enabled smart glasses 'very high', and around 29% of surgeons rated its usefulness as 'high' (Borgmann et al, 2017). Gans et al (2015) demonstrated six cases of AR-assisted surgery in critically ill patients. Operators who participated in the study provided positive feedback regarding the use of AR in the surgery, saying that the ability to focus on the surgical field provided a major benefit to the operator implementing the procedure (Gans et al, 2015). However, in the absence of larger data on the use of AR devices in surgery, the effectiveness of AR in improving surgical practices and the operators' productivity needs further testing before any definitive conclusions can be drawn. Lan et al (2018) also conclude that an AR-supported surgery was a success. The procedure was considered accurate and quickly implemented, which could significantly shorten the duration of surgeries and reduce re-operation rates (Lan et al, 2018). A literature review by Meola et al (2017) on surgeries conducted with the support of AR has found that AR can be a supportive tool for minimally invasive surgeries; however, the study found that there are few prospective randomised studies available and that technical improvements to the technology are required.

VR can also augment surgical planning processes by improving the surgeon's spatial understanding of the patient's anatomy prior to the procedure (Kockro et al, 2016). In

University Hospital Mainz, University Hospital Zurich and Hirslanden Hospital in Zurich, more than 115 procedures in 105 patients were carried out with the help of a VR system from 2006 to 2015 (Kockro et al, 2016). The VR surgical planning system was also associated with excellent clinical outcomes (Kockro et al, 2016).

In urban planning AR tools have potential to increase the quality of participation procedures by making planning processes and envisaged designs more understandable for laypeople (Reinwald et al, 2014). An example is the PEAR project, which sought to increase public engagement in urban planning in Sweden through an AR mobile app voting system connected to Twitter. Although the app demonstrated the feasibility of the concept, it had limited success in its efforts to increase public engagement (Alissandrakis and Reski, 2017). One study conducted two field tests in Vienna to evaluate the effectiveness of an AR mobile application to increase participation in urban planning processes (Reinwald et al, 2014). The study found that participants reported that the use of a combination of AR and real-world representation of plans increased the efficacy of understanding planning projects (Reinwald et al, 2014).

3.2 Implications for work and employment

Box 6. Summary of potential implications for work and employment

- It is unclear whether VR/AR training programmes yield better performance outcomes in comparison to traditional training methods.
- VR/AR could enable vocational rehabilitation of individuals with disabilities and trauma.
- Evidence that VR/AR could lead to job losses is limited, but it could result in lower employee bargaining power and in decreased worker autonomy
- VR/AR solutions could contribute to improved public engagement and to better understanding of and influence on public/consumer behaviour within the retail sector.
- VR/AR could enable improved employee interaction (including increased empathy and perceptiveness).
- VR/AR could:
  - reduce employee workload in sectors that rely on manual tasks, as well as simplify workplace tasks
  - improve worker safety, as well as create new safety challenges in sectors that involve high-risk environments.
  - support team-working processes (including increased situational awareness and improved collaboration).
  - potentially contribute to the reduction of risks and uncertainty in such sectors as architecture, real estate and engineering.

3.2.1 Employee performance

The great majority of the peer-reviewed literature examined involved studies that demonstrate the feasibility of VR/AR as a tool for training purposes. However, there is mixed evidence regarding VR/AR training programmes obtaining better results than other methods. Given that these studies have not yet been tested for longitudinal effects, the long-term implications of the evidence presented are not yet known.

- A survey of 32 health practitioners who tested an AR training system for health care rated the system positively, with the majority of respondents saying that they agreed that the system gave learners an authentic experience, provided engaging interaction, enhanced the simulation, enhanced learning, encouraged critical thinking and decision-making, inspired dialogue during debriefing and assisted the learner to understand a concept or skill (Carlson and Gangnon, 2016).

- An evaluation of an AR-enabled military decision-making process training system, which involved 40 teachers and personnel in the Taiwanese Army Command and Staff College, sought to explore users' acceptance of training systems that make use of AR to support experiential learning (Mao et al, 2017). The study found that the AR system's novelty was attractive to users and changed the traditional instruction system of army tactics (Mao et al, 2017). The attractiveness of the system was found to hold learners' attention and to stimulate discussion effectively (Mao et al, 2017).
- A study by Gavish et al (2015) conducted an evaluation of an AR-facilitated training platform and a VR-facilitated training platform compared with a control group of workers trained through traditional methods. The study found that the mean duration time for training in the AR and VR training platforms was longer than for that in the respective control groups and did not yield better performance outcomes , contrary to what had been hypothesised (Gavish et al, 2015). However, one limitation of the study was the participants' lack of experience with the platforms or technologies, so the authors note that AR and VR training may become more efficient in the future, once these technologies become more commonplace and exposure to these technologies is increased (Gavish et al, 2015). The study also investigated how AR and VR training platforms affect error rates and reported low unsolved error rates - with 80% of participants performing with no errors, which the authors suggest means that these platforms are valid training tools (Gavish et al, 2015).
- Another study, held in the Center for Virtual Reality at Chemnitz University of Technology in Germany, sought to compare the effectiveness of VR training in comparison to presentations in Microsoft PowerPoint for health and safety education and found that VR did not increase the retention of safety information (Leder et al, 2018).
- A systematic review of 27 studies on AR medical training also found limited evidence to support the effectiveness of AR training (Barsom et al, 2016).
- Akçayır and Akçayır (2017) found mixed results regarding AR's role in managing cognitive load. Although AR contributed to decreasing cognitive load faced by employees in some scenarios, it was deemed to increase cognitive load in other situations.
- A literature review by Pelargos et al (2017) concludes that the advantages of VR/AR in training are contingent upon the design of the representational fidelity of the 3D virtual environment and its interactive potential.

The mixed evidence of improved training outcomes through VR/AR indicates that the effectiveness of VR/AR systems is likely to be dependent on such factors as their realism, usability, and user-centric design and on future advancements in the functionality of VR/AR devices. The various feasibility studies examined here indicate that, although VR/AR assisted training can be a support tool to traditional classroom-based learning, it is not yet a sufficiently robust alternative to traditional classroom-based methods. In the future, VR/AR training systems may be more desirable if technical challenges are overcome.

3.2.2 Vocational rehabilitation of individuals with disabilities and trauma

Disadvantaged groups, such as people with disabilities or mental disorders, can enter into vocational rehabilitation through VR training environments (Tsang and Man, 2013), which could support their integration in the workplace, as also one interviewed European researcher suggested. One study suggested that VR training can be more effective than conventional training in helping patients with schizophrenia to return to work due to the failure-free and game-like environment that virtual reality presents (Tsang and Man, 2013). Whereas patients reported frustration when failing in real work environments, virtual-reality training was reported by Tsang and Man (2013) to help patients cope with challenges with higher self-efficacy. Another feasibility study found that memory functions of people who experience traumatic brain injury was found to improve through VR problem-solving training (Man et al, 2012).

For personnel working in jobs that expose them to high risk of PTSD, treatments trialling VR-facilitated exposure therapy are being explored. For example, one study piloted a Virtual Iraq or Virtual Afghanistan scenario aimed at treating veterans with PTSD (Cuckor et al, 2015). The study surveyed clinicians on the treatment and found that the VR-supported therapy system received a positive response from clinicians due to the system's ability to provide an objective and consistent format for documenting and analysing the effects of stimuli on the client, which can be combined with analysis of the client's self-reported reactions (Cuckor et al, 2015). Moreover, the system could improve take-up of treatment by augmenting its appeal (Cuckor et al, 2015). A proof of concept found that VR exposure therapy was effective in delivering treatment, with significant reductions in pre-to-post-treatment PTSD (Loucks et al, 2018). A randomised controlled trial that investigated the effects of VR exposure therapy on active-duty soldiers also found a reliable change in PTSD symptoms; however, the study did not find VR treatment to be more effective than other treatments, such as prolonged exposure therapy (Reger et al, 2016). A randomised controlled trial of VR job interview training for veterans with PTSD found that VR trainees showed significantly greater performance scores and a moderate increase in confidence, which could support job interview skills and lead to improved employment outcomes (Smith et al, 2014).

3.2.3 Job redistribution

Two interviewees[15] raised concerns regarding the disappearance of some jobs as personalised services reduce the need for human operators for some tasks; it is unclear to what extent these fears will be realised in the future, although some disruption is likely. For example, in the tourism sector, AR devices could potentially replace tourist guides as AR-powered mobile devices grow in popularity, along with the demand for more personalised services across the service sector (Jung and Han, 2014). In retail, Demirkhan and Sphorer (2014) note that VR/AR's role in developing self-service systems appears to be an inevitable trend, which could reduce reliance on service personnel and change the operation of complex systems, from dedicated human operators to self-sufficient customers. However, one interviewed industry expert thought that it is more likely that new job roles will be created and lead to increased workforces in organisations and that the technology is more accurately envisaged as a tool that augments the skills of retail personnel than a threat to their livelihoods. The same interviewee suggested that the use of VR/AR can also lead to increased demand for neuro-cognitive and psychology skill sets in the retail sector.

One interviewed industry expert noted that, in order to protect the employees from job losses, there is a requirement for governments to manage the flow of employment distribution, as well as the flow of skills and talent, as labour market demand shifts. The same interviewee also asserted that skills supply and demand currently are not synergised, because employers and governments recognise the requirement for digital skills, flexibility and innovative behaviour, but formal education fails to equip incoming labour forces with skills (Cedefop, 2018).

[15] Based on separate interviews with an industry expert and another expert consulted in the framework of the study on virtual and augmented reality

According to the same interviewee, a potential consequence of data-led management of tasks is for the labour force to unlearn particular skills due to increased reliance on the technology. This suggests that, as task provision becomes increasingly prescriptive, employees may focus on minutiae and resort to passive task acceptance in work processes, instead of the use of independent thinking and proactive problem resolutions - both of which are critical attributes in service sectors.

3.2.4 Business practices

As the trend in targeted advertisements and personalised services continues to grow, large volumes of data will continue to be gathered on consumer preferences and behaviour, which will allow products and services to be developed to be more attuned to consumer demand. This has implications for how organisations use data and market their services to differentiate their offerings to consumers (Demirkan and Sphorer, 2014).

VR/AR could increase firms' competitive edge and result in higher profits if marketing strategies are able to entice consumers more effectively (Abraham and Annunziata, 2017; Poushneh and Vasquez-Perraga, 2017; Kiryakova et al, 2017). In particular, the entertainment and personalisation factors of utilising VR/AR, for example, for mobile shopping applications, can change how retailers compete with each other on the high street and gain competitive advantage (Dacko, 2017). This has the potential to add a number of back-office, data analytics-driven jobs to consumer-facing services sectors, including retail and tourism.

In the tourism and cultural heritage sectors, VR/AR can engage consumers more effectively through interactive visualisations of displays (Leovaridis and Bahna, 2017; Jung and Han, 2014). For example, in Spain, the Gaudi museum's Casa Batlló is an AR museum guide with visual and auditory functions that visitors can download as a mobile application on their smartphones (Casa Batlló, 2018). The app superimposes furniture into empty museum rooms and allows visitors, including those who may be restricted by language, visual disabilities, hearing disabilities and reduced mobility, to receive educational information on the cultural heritage site (Casa Batlló, 2018). A study by Huang et al (2016) that used a sample of more than 186 participants, found that users experienced enjoyment using a 3D virtual tourism site visit due to the perceived autonomy of the experience. A similar trial conducted in Hong Kong with 202 participants and in the UK with 724 participants found that attitudes on visit intention increased as a result of the introduction of VR tourism content (Tussyadiah et al, 2018). Moreover, a VR experience prototyped by Ticino Tourism, a destination management organisation in Switzerland, found that the use of VR contributed to the formation of strong memories (Marchiori et al, 2017), which, the authors propose, could be used to enable improved understanding of consumer behaviour, which, in turn, could be used to design more effective and engaging VR content. The use of VR/AR can thus change the role of those involved in the tourism sector to increase the emphasis on facilitation and personalised attention to the tourists, with the job of information provision being left to the devices.

In the retail sector, VR/AR-facilitated devices could reduce retailers' return rates, which generate transportation costs - particularly for large items, such as furniture (Dacko, 2017). For this reason, the furniture retailer IKEA has trialled the IKEA Place app, which provides consumers with previews of the products in their own home, allowing them to test the fit and aesthetic of products before purchase and delivery (Reynolds, 2018).

In technical support services, where maintenance often takes up over 30% of operating costs, AR systems that enable remote collaboration between the manufacturer and the on-site technician could help reduce costs by reducing response time of technical support systems. One study, by Mourtzis et al (2017), demonstrated an AR system that can be used for this application, but it did not demonstrate evidence of reduced costs.

The use of AR can also have implications for practices in the hospitality sector. Rollo et al (2017) report on an AR tool, ServAR, that can be used to increase the accuracy of food portion sizes in the hospitality sector. They report that using AR improved the accuracy and consistency of estimating standard serving sizes (Rollo et al, 2017).

Some evidence demonstrates the viability of VR/AR solutions in simulating realistic environments that can inform business model and task management strategies to make them more efficient. Oh et al (2017) developed a service test laboratory, called s-Scape, to demonstrate how it can be used to test a used-car sales service.

3.2.5 Workplace interaction

An interviewed European researcher suggested that immersive technologies, such as VR/AR, can also help generate empathy and allow users to experience the perspectives of others. For example, a project by the University of Malta is exploring how VR can be used by teachers to understand the experiences of students with autism. According to the interviewee, the project sought to support the professional development of teachers by creating a six minute VR experience that gave the teachers first-person insight into the experiences of children with autism in a classroom. The same interviewee reported that the purveyors of the project are also exploring how the same educational concept could be applied to scenarios of pupils and teachers working in multicultural classrooms. The challenge that the project sought to address was the possibility that the teachers may not recognise signs or triggers that could lead to adverse effects on students. According to the same interviewee, this is likely to be increasingly important as classrooms have more diverse representation of gender, ability, and culture. If teachers are not able to empathise with the experiences of pupils they could be unaware of signs or triggers that could affect pupils in adverse ways. For example, the interviewed European researcher reported that with autistic children, strong gesticulation was found to trigger anxiety, an aspect of their experience that teachers failed to fully take into consideration until they experienced the VR education tool. According to the same interviewee, an evaluation of the project, which involved 150 responses, found that teachers considered the tool to have increased their ability to empathise with pupils.

Box 7. Virtual/augmented reality, wearable devices, Internet of Things, and big data: A cross-technology perspective

The immersive nature of experience offered by VR/AR technologies lends itself to interaction and integration with a number of existing and emerging technologies such as smartphones, wireless connectivity, wearable devices, Internet of Things (IoT) enabled devices in industrial settings (Industrial IoT or IIoT devices), and big data analytics. Smartphones offer an easy access to immersive environments when combined with head mounted displays such as Samsung Gear VR and HTC Vive (Kahney, 2018; Violino, 2017). On the other hand, devices such as Microsoft HoloLens and Oculus Rift provide a headset with an integrated VR/AR immersive environment and are examples of the blurring boundaries between VR/AR and wearable technologies (Hempel, 2015; Rubin, 2016). In contrast to such head-mounted displays, the immersive experience offered as part of training in defence and aviation sectors is likely to increasingly rely on advances in display technologies such as high-resolution micro-organic light emitting diode (OLED) displays and photo-realistic creation of virtual environments (Lele, 2011; Turk, 2018).

A key component of the VR/AR experience is wireless connectivity in the form of WiFi, Bluetooth, and 4G LTE particularly for gaming and entertainment sectors to provide an interactive online and streaming experience (ABI Research, 2018). Combined with the existing patterns of use, increased demand for wireless access to VR/AR environments in workplaces is expected to lead to increased research and investment in low latency and ultra-reliable wireless connectivity such as Low-Power Wide-Area Networks (LPWAN) and intensify with the introduction of 5G (Elbamby et al, 2018; Qualcomm Technologies Inc.,2018).

When the use of VR/AR technologies in sectors such as logistics, engineering design, and healthcare sectors is concerned, their use is expected to take place in conjunction with devices which are IoT-enabled in industrial settings (Vaccari, 2015). For service sectors such as consumer, marketing, education, and healthcare such devices are conduits of valuable data for analytics functions and may form a part of the big data analytics of business functions and models (Olshannikova et al, 2015). Since the introduction of AI capabilities in VR/AR environments is at a very early stage (Cipresso and Riva, 2015), the extent to which integration of AI and VR/AR would aide working practices in services sector remains unknown as of 2018.

Source: ABI Research, 2018; Cipresso and Riva, 2015; Elbamby et al, 2018; Hempel, 2015; Kahney, 2018; Lele, 2011; Olshannikova et al, 2015; Qualcomm Technologies Inc.,2018; Rubin, 2016; Turk, 2018; Vaccari, 2015; Violino, 2017

3.2.6 Employee workload

Some firms report that VR/AR solutions have brought about a reduction in manual, repetitive tasks. For example, Mitsubishi Electric (2016) reports to have developed a maintenance and inspection support system that utilises smart glasses to reduce workers' workloads. In another study, in Germany, an AR testbed for air traffic controllers was found to reduce workload due to the reduction in 'headdown-times' (Hofman et al, 2012). The study identified a problem - namely, the difficult and stressful situations that air traffic controllers are normally confronted with when coordinating information delivered to work desks from controllers and acoustic interaction with pilots (Hofman et al, 2012). The study then piloted an AR system that added an AR layer to the windows of an air traffic tower to align virtual information with the real environment outside the windows, which decreased the workload of air traffic controllers (Hofman et al, 2012). In the health services sector, a proof of concept study by Abhari et al (2015) reports that the use of an AR environment can enable novice physicians to practice and improve their basic spatial reasoning skills, contributing to increased cognitive ability to perform neurosurgical planning. Furthermore, in the defence sector, Lackey et al (2016) state that soldiers who participated in a VR training regimen tended to experience lower stress and lower workload when performing the live version of the task.

3.2.7 Worker autonomy

Workers in the knowledge economy[16] are faced with increasingly complex and potentially unpredictable tasks that require enormous amounts of data, while juggling heavy workloads (Mariani et al, 2017). VR/AR platforms can present opportunities to simplify tasks by offloading some of the worker's tasks and responsibilities to the device (Mariani et al, 2017). One interviewed industry expert described the effects of introducing VR/AR solutions in his company as creating a very 'task-driven' way of working, describing how workers essentially think less actively about the task ahead and instead become accustomed to being passive receivers of tasks through the device. For example, repetitive tasks, such as inspecting and diagnosing an almost imperceptible crack in a jet engine turbine, or tasks that require workers

[16] 'Knowledge economy' is a type of economy in which economic value is generated through the creation and dissemination of knowledge, rather than tangible goods. See Murray and Greenes (2013) and KSS Architects (2017).

to find the optimum route for a delivery truck, could benefit from offloading several steps required in these tasks to machines (Mariani et al, 2017). In such sectors as retail, some VR/AR solutions show promise in eliminating time-consuming tasks, such as organising shelves and inventories, by supporting the visual display of products in a store's inventory without occupying a considerable amount of space and compelling workers to arrange and re-arrange displays as customers sample products (Oh et al, 2004). As a result, the use of VR/AR could reduce the decision-making burden on workers by providing easier access to information and also reduce the need to engage in mundane, pre-defined tasks without any significant variations.

According to some interviewees[17], there may also be trade-offs regarding decreased worker autonomy as tasks and work processes become increasingly data-driven and task-driven. One interviewee also noted that, as organisations increasingly depend on data-led management techniques that design tasks to maximise efficiency, productivity and outputs, there is a risk that space for the human operator to demonstrate free will and ingenuity could be reduced when it comes to work-related tasks and problem solving, according to an interview with an industry expert.

As worker autonomy decreases, the interviewed industry expert highlighted that the productivity and quality of work created by each employee is also likely to be largely affected by constraints beyond the employee's control, such as software and data-led processes. The same interviewee reported that there is also some ambiguity regarding how much autonomy workers will have if they are compelled to use company-mandated VR/AR devices. In such a scenario, the workers would largely follow instructions specified through the VR/AR devices and thus may not have any decision-making powers.

The efficiencies gained by employing VR/AR solutions in the workplace may be seen in changes in the day-to-day types of tasks that employees are likely to face. As the time required for employees to process environmental data is reduced by VR/AR solutions, employees can focus more on other, less mundane aspects of their jobs (Doolin et al, 2013).

3.2.8 Worker safety and mental health

VR training environments can contribute to improved worker safety by removing workers from potentially harmful or dangerous environments or preparing workers for high-risk environments. Before applying the task in real life, trials could be conducted in a safe, simulated environment (Cohen and Gretczko, 2017) that lowers risk to the individual, the individual's colleagues and the organisation. For example, in preparation for high-risk environments in fire services (Williams-Bell et al, 2015), simulated virtual environments that depict real-world complexities can allow trainees to see and interact with training environments as if they were real. Williams-Bell et al (2015) note that VR training environments can test cognitive spatial tasks in realistic scenarios. However, they also note that the VR technologies provide a programmed set of simulated scenarios and are not able to fully replicate the unpredictability and dynamism of the situations that fire fighters are likely be confronted with in the real world.

One interviewed industry expert suggested that, as worker productivity increases through AR-facilitated systems and as mundane tasks are phased out of work, workers may only face highly demanding, complex and intellectually challenging tasks. The same interviewee posited that continuously working on complex tasks can result in increased stress levels for workers. Depending upon the functionalities of the solution, the VR/AR device can also

[17] Based on separate interviews with an industry expert and an European academic expert

enhance the performance of complex tasks or alleviate challenges, so the consequences are at least partially determined by the solution's design, according to the same interviewee.

In addition, the same interviewed industry expert pointed out that the growing prescriptiveness of task allocation by superimposing instructions constantly within workers' line of sight through AR can potentially lead to work cultures that isolate individual employees in siloed workstations.

According to interviewees[18], despite the perceived risk of motion sickness and nausea due to persistent use of VR devices, as yet, there is limited evidence of simulator sickness caused by VR in the workplace context (see also Vovk et al, 2018). An interviewed European researcher suggested that out of 300 participants in their study, only 2 participants (less than 1% of the sample) experienced simulator sickness. Reduced user immersion time in the simulation (Koomen, 2018) or the maintenance of a steady frame rate below 60-70 frames per second was found to prevent simulator sickness, according to an interviewed industry expert. One evaluation on simulator sickness caused by VR found that motion sickness disproportionately affected women (77.78%), as opposed to men (33.33%) (Munafo et al, 2017). This could mean that women may be at greater risk in workplaces that rely on VR/AR solutions extensively.

3.2.9 Inter- and intra-organisational collaborations

VR/AR could support team-working processes. For example, VR could aid in enhancing communication and team understanding of ideas. This could ensure that team members have shared situational awareness and can improve their oral and written communication.

In the military or police sectors, where operational teams rely on quick exchanges of context-related information, the main mode of communication is oral, but under time pressure oral communication risks being understood or interpreted differently or being unequally distributed among team members (Datcu et al, 2015). Wrong information could misinform choices in crisis scenarios and lead to unsafe outcomes for operational teams or civilians (Datcu et al, 2015). AR systems could facilitate more effective exchange of information and contribute to improved situational awareness across operational teams (Gans et al, 2015; Datcu et al, 2015). In one study, Datcu et al (2015) piloted an AR information exchange system called Distributed Collaborative Augmented Reality Environment with the Dutch police and the Netherlands Forensic Institute. The AR system was developed to support virtual co-location of distributed users through AR, which allowed local users to stream the objects in their line of vision as they moved in the physical environment with a remote user during three separate scenarios involving forensic investigation, VIP protection and domestic violence (Datcu et al, 2015). The participants of the study evaluated the system's ability to improve communication and team situational awareness and indicated that the system had a positive effect on the team's collaboration skills (Datcu et al, 2015).

Similar approaches to enhancing collaboration are being tested in the automotive and defence industries. For instance, Ford (Designboom, 2017) and Raytheon (Australian Defence Magazine, 2017) are testing VR-facilitated collaborative environments that facilitate collaboration among designers, engineers and other collaborators. Raytheon's VR Cave is anticipated to lower costs, by reducing the need to travel to the same location to collaborate, and to make systems integration processes of complex systems engineering smoother than before.

[18] Based on separate interviews with an European researcher and an industry expert.

In emergency health services and combat care, a proof of concept evaluation of an AR device for first responders demonstrated the feasibility of an AR intelligent dashboard that connects an incident commander with emergency service teams in the field (Vasell et al, 2016). Participants in the trial rated the usability system a 5 out of 5 (with 5 being ‘high’) for all criteria except for the quality of the audio and video communications, which was rated a 3 out of 5 (Vasell et al, 2016). Another feasibility study indicates that telementoring appears to be a suitable method of providing surgical support across dispersed teams of medical support providers (Miller et al, 2018). A demonstration of an AR telementoring system that connected experienced surgeons with remotely situated and less-experienced surgeons found that the less-experienced surgeons were able to complete tasks with greater accuracy (Andersen et al, 2017). In other telementoring systems, the restrictions on communication and visualisation can constrain the effectiveness of the system, whereas the strength of the AR-enabled system, called ‘The System for Telementoring and Augmented Reality’ (STAR), is its ability to reduce the need and time required for shifting focus from monitor to operating field due to the overlaid instructions and annotations on the screen (Andersen et al, 2017; Anton et al, 2016). This method is envisaged to provide a more effective solution for telementoring by allowing experts to obtain more situational awareness, provide closer assistance at the point of injury, and reduce delay of assistance (Andersen et al, 2017). Additionally, the advantage of AR-facilitated telemedicine systems is their ability to improve clarity and provide clear visual instructions to the local caregiver (Anton et al, 2016). The devices presented in Andersen et al (2017) and Anton et al (2016) are both tablet-based; however, both authors suggest that a wearable AR device could further improve the outcomes of the AR-facilitated telementoring by proving a more immersive experience and freeing users’ hands.

3.2.10 Design and engineering processes

VR/AR can also contribute to the reduction of risk and uncertainty in such sectors as architecture, real estate and engineering by allowing professionals, such as consultant engineers, to use VR-facilitated visualisation and modelling techniques to create complex and informative simulations for large and expensive infrastructure projects and to avoid additional costs (Whyte, 2003). VR/AR visualisation techniques can be helpful in illustrating the envisaged design in a compelling way that heightens the likelihood of clients’ acceptance of proposed designs. According to an interview with an industry expert, VR simulations could help reduce the requirement for product design iterations, thus reducing time to market, and aid in producing superior products, thus changing the scheduling and managing of design work and reducing workers’ capacity constraints. One study surveyed the responses to VR visualisations as opposed to static photo visualisations of a proposed wind turbine and found that respondents found it easier to evaluate the proposed changes to the environment, as well as how their behaviour might change, through the VR visualisations (Teisl et al, 2018).

In design occupations, for example, in architecture, environmental planning or car manufacturing, VR-facilitated design platforms have been successfully piloted to support the design process by creating a shared understanding of conceptions of the planned use of space. For example, Rahimian and Ibrahim (2011) conducted a feasibility study on the impacts of VR 3D sketching for remotely situated designers and found that collective cognitive understanding and collaborative processes and design creativity were enhanced by the VR design system. Design platforms could also include navigation within an on-screen VR environment (Portman et al, 2015). Wolf et al (2017) have also conducted a study trialling a VR-facilitated method of navigating the virtual environment through a VR prototype compared with a 2D screen. Participants found that the VR environment, as well as movements, such as walking, sitting down and hand manipulation, appeared more authentic (Wolf et al, 2017).

3.2.11 Employee bargaining power

One interviewed industry expert contended that, as technologies that enhance human productivity and flexible working conditions, such as VR/AR, proliferate, there is a risk that there will be fewer opportunities for workers to organise into trade unions. In this interviewee's opinion, such an increased drive for productivity can result in labour forces that have reduced negotiation rights and are likely to be locked out of participation in decision-making by businesses.

Box 8. Virtual/augmented reality and the risks to security and privacy

Depending on the capabilities of the hardware used to deliver the immersive experience, VR/AR technologies may pose physical as well as digital risks. When used in conjunction with a headset, unknown to the user, VR/AR technologies can collect information about the user through the camera, the microphone, and also track the user's precise location information (topanga, 2018). Even where anonymised data are collected, the underlying algorithms have the capability to potentially identify the user by cross-referencing data sources with individuals' 'digital traces'. Research suggests that such approaches can be remarkably accurate in approximating and collating personal data (see, for example, Lambiotte and Kosinski, 2015). Additionally, the users may also be required to register with the devices' makers and thus provide personal and payment-related information to a third party (Roesner et al, 2014). As the technologies provide an immersive experience they can have a disorientating effect on the user and may diminish their situational awareness, outcomes that increase the risks to the users when engaged in a mixed reality environment (Fineman and Lewis, 2018). With rise in malware specifically targeting the underlying VR/AR software platform, the technology can be vulnerable to cyber attacks through vulnerable cloud environments (topanga, 2018). Since VR/AR environments and displays often rely on cloud computing to provide a high graphical density immersive experience, large-scale cyberattacks could result in lost, distorted or compromised personal data for users, whether at work or at home.

The introduction of the EU's GDPR offers to improve legal framework and protection for personal data and makes collecting and processing these data without explicit user consent unlawful. However, Jülicher (2018) argues that even those users who take it upon themselves to read multipage privacy policies have difficulties in assessing what actually happens to their data. In some cases these risks are mitigated for employees. Some of the transpositions of the EU GDPR into Member States' national law explicitly recognise workers' rights to privacy when using their employers' digital tools. The Organic Law on Data Protection and Digital Rights Guarantee (LOPDGDD) enacted by the Spanish parliament in 2018 is an example of this kind of legislation (Jefatura del Estado, 2018).

Source: Fineman and Lewis, 2018; Jefatura del Estado, 2018; Jülicher, 2018; Kirk, 2014; Lambiotte and Kosinski, 2015; Roesner et al, 2014; topanga, 2018

4. Conclusions

This study aimed to understand the implications of virtual/augmented reality as a potential game-changing technology area to the services sector in Europe. The findings suggest that VR/AR technologies are at a relatively early stage of adoption in the services sector. Although the outcomes related to jobs, required skills, working conditions, and workplace practices in the services sector are still emerging and vary significantly depending on the needs of the different sectors, early adoption trends and high-level implications can be discerned, as has been outlined in chapters 2 and 3 of this working paper. This section summarises the key findings in relation to the primary objectives and the main elements of the conceptual framework outlined in chapter 1.

4.1 Applicability of VR/AR technologies in the services sector

A significant amount of the VR/AR technology development and adoption at this stage is targeted at the consumer rather than at enterprise activities. Although the technologies are gaining traction in specific segments of the services sector, such as education, retail, marketing, education, and healthcare, their wider adoption and the rate at which the adoption takes place would depend on the success of the ongoing pilot activities. In sectors such as defence and aviation, immersive VR/AR is likely to be used in conjunction with existing simulation approaches. In sectors such as entertainment, gaming, tourism or design, being services with well-established industry practices on the use of simulation, immersive uses of VR/AR are likely to see increased application given the flexibility and options VR/AR offers in simulating a broad range of real-life outcomes.

4.2 Potential implications of VR/AR technologies on productivity, output and work organisation

Since the technology is at an early stage of deployment, the evidence on the extent to which the technology would change work practices is not sufficiently clear. Early evidence suggests that the use of VR/AR could contribute to improved employee satisfaction and productivity. Whether such outcomes would be sustained in the long term, once the novelty of the technologies wears off, is not clear at this stage. Long-term use studies and independent evaluations of VR/AR technologies in the workplace and their effect on workers are necessary to understand the gains these technologies could offer to worker productivity and well-being, and how these technologies could change the operations in the services sector.

4.3 Potential implications of VR/AR technologies on employment and skill levels

Expert opinion differs on the extent to which the technology could see widespread adoption and whether it could displace existing jobs given investment costs related to the hardware and the connectivity requirements. In sectors such as retail, marketing, advertising, or tourism, where existing jobs rely on personalised services, experts suggest that the need for human operators may decrease in the medium term. However, the cost effectiveness of displacing human operators and whether the use of VR/AR could sustain consumer interest in such sectors is not yet fully understood. Some experts highlight how too much emphasis on centralised administration through the use of augmented reality systems could result in decreased worker autonomy and thus lower satisfaction and productivity in the long run. However, given that the technology is in the early stages of deployment, the findings on future skills needed and the changing nature of employment are not sufficiently conclusive in the immediate term. The long-term implications of VR/AR technologies for employment are only likely to be better understood subject to wider deployments of the technology in the services sector.

4.4 Potential implications of VR/AR technologies on working conditions

In the medium term, the key impacts of VR/AR technologies are likely to be in assisting workplace practices, helping workers provide more information about their working conditions, and contributing towards training workers about specific scenarios in a simulated environment. Available evidence suggests that AR-enabled systems are being piloted or deployed for initial uses in sectors such as health and healthcare (including surgical procedures), real estate, administrative and support services, retail sector (for advertising and marketing), and education (for improved instruction and inclusion of participatory elements). The use of VR appears to be focussed on training of personnel about high-risk environments, including jobs that involve hazardous situations, such as policing, fire and rescue services, and emergency services. In each such scenario, initial evaluations during the pilot phase indicate that VR/AR systems are seen to reduce costs and potentially contribute to increased safety and situational awareness and enhanced collaborative opportunities. As in the case of other pilots testing VR/AR technologies, further independent studies and longitudinal assessments of the technologies in the workplace are needed to better understand the changes to working conditions and work practices.

5. Real-world case examples illustrating the applicability and potential implications of VR/AR

Three examples of 'real-world' applications of VR/AR technologies are presented below. The examples are intended to illustrate rather than assess the applicability and implications of VR/AR in the services sector. Instead of offering insights on a broad range of impacts for VR/AR (as has been presented in chapter 3), the case examples are meant to succinctly exemplify potential or realised impacts in one or two (or more, where information is available) areas. The examples are meant to enrich the overarching analysis presented in this working paper by offering a real-life illustration of how these applications have had or will have an impact in practice.

Table 4: Case example 1: Augmented reality in DHL supply chain logistics

Augmented reality in DHL supply chain logistics
Location: Germany
Example service sector(s) the case example applies to: • Wholesale and retail trade (NACE sector G); • Transportation and storage (NACE sector H); • Administrative and support service activities (NACE sector N).
Background and overview of the technology: DHL Supply Chain is the contract logistics specialist of the Deutsche Post DHL Group and claims to have more than 500 years of experience in logistics (Deutsche Post DHL Group, 2017a). They offer services in warehousing solutions, transport solutions, management services and integrated solutions. This includes international supply chain consultancy and design, managing the operation, and supply chain visibility. It also includes freight and destination management. DHL Supply Chain operates in more than 50 countries worldwide (Deutsche Post DHL Group, 2017a). In 2014, DHL Trend Research produced a paper on the potential uses of augmented reality in logistics, which led to DHL Supply Chain's decision to invest in augmented reality (Pearce, 2017). As of 2018, after trials were completed in 2017, AR glasses have passed the pilot stage and have been part of everyday processes in DHL's warehouses in Germany (Deutsche Post DHL Group, 2017b). The trials took place in mainland Europe, the USA, the UK, Australia and New Zealand. As of 2016, privacy laws did not allow vision picking (that is, scanning the barcode or other similar coded information through an inbuilt barcode scanner in an AR device) in most countries (Heute, 2016). According to an interviewed DHL representative, the company uses both Vuzix and Google Glass Enterprise, although workers prefer the ease and comfort of use of the latter.
Illustrations of potential socioeconomic implications: The AR glasses display order-picking instructions, such as where the items are located and where they ought to be placed, within the workers' line of vision, which frees pickers' hands from the need to use paper instructions and provides an intuitive solution to support logistics tasks (as reported by the same interviewee; see also Deutsche Post DHL Group, 2017b). The 2014 DHL Trend Research report noted that paper-based solutions were found to be fundamentally slow and error prone (Glockner et al, 2014). According to the interviewed DHL representative, DHL envisaged that, by freeing pickers' hands from the need to use paper instructions, the worker's comfort and efficiency would improve in warehouse operations. During the trials, productivity was seen to increase by 15% (Deutsche Post DHL Group, 2017b), and the accuracy of task execution also increased, as the same interviewee highlighted. The interviewed DHL representative noted that planning processes have not been affected, but, as a supportive tool, AR has optimised processes. In one DHL site in the Netherlands, productivity outcomes were described to be 10% higher (Heute, 2016). Increased efficiency can contribute to an increased competitive edge in the logistics industry (Deutsche Post DHL Group, 2017b). AR is also highlighted as part of plans to generate improvements in the warehouse planning process. With augmented reality, warehouse processes could involve new value-added services, such as product assembly, labelling, repacking and repair (Glockner et al, 2014).

Training processes for new and temporary staff in logistics processes are also projected to benefit from the integration of AR tools to support mentoring processes (Glockner et al, 2014). DHL reports that, since its introduction of AR glasses, training and induction processes are completed more quickly (Heute, 2016; Deutsche Post DHL Group, 2017b).

An interviewed DHL representative stated that the company uses a number of temporary labour personnel - particularly during peak season - and the technology allows the company to make use of temporary labour without requiring expensive and long durations of training.

Beyond the afore-mentioned direct benefits, further benefits are expected by DHL once the technology matures within their processes. For example, improvements in the picking process, which involve the order preparations processes, are envisaged by the company to have knock-on effects of reducing costs (Glockner et al, 2014). Picking errors are already typically low, but errors can result in high follow-up costs (Glockner et al, 2014). Delays and errors can add up over the day and have a major impact on operating costs. DHL is also exploring the expansion of the applications of augmented reality-supported glasses to such areas as maintenance and dimension calculations (Deutsche Post DHL Group, 2017b).

Some literature has also highlighted the prevalence of simulator sickness when using augmented reality training (Vovk et al, 2018). According to the Netherlands' Trade Union Confederation, there is also a danger of employees experiencing more stress or work pressure, as well as for performance targets to be raised and for an overall decrease in worker autonomy due to the increasing dictation of behaviour by software through technology, such as AR/VR (Heute, 2016). A study by the work and health consultancy HumanCapitalCare did not find that participants in vision-picking processes suffered from physical strain or radio-frequency radiation; however, a whole day of vision picking can cause headaches (Heute, 2016). DHL has found no indication that the introduction of AR in the picking process, and the consequent increases in productivity, could lead to job cuts in this industry. The interviewee explained that there is a persistent shortage of workers in the logistics sector. The interviewed DHL representative did not envision the need to reduce employee count due to this shortage even if productivity increases.

In the future, DHL may expand the use of AR to the transportation of parcels, to support drivers' navigation; however, according to the same interviewee, this has not yet been implemented by the company due to the safety concerns around driver's vision. The working conditions of drivers throughout the logistics supply chains could potentially be improved by displaying information within their field of vision through AR; the key advantage would be the reduced need for drivers to take their eyes off the road (Glockner et al, 2014), which would also potentially lead to increased safety.

Table 5: Case example 2: Virtual reality training in KLM

Virtual reality training at KLM
Location: the Netherlands
Example service sector(s) the case example applies to: • Transportation and storage (NACE sector H); • Wholesale and retail trade (NACE sector G); • Administrative and support service activities (NACE sector N).

Background and overview of technology: Before the KLM VR training system was initiated, safety training at KLM was implemented through verbal instruction and online courses in classroom-like settings for large numbers of employees (Goodwin, 2017). KLM began exploring how computer games techniques could be implemented in learning techniques for staff in collaboration with the Delft-based company Warp Industries after a manager at KLM Engineering and Maintenance probed whether there was a better and more effective way to implement training for engineers. Overall, according to an interviewed KLM representative[19], around 1,000 out of a total of 34,000 KLM personnel use the VR training system on an annual basis.

According to the same interviewee, KLM developed a VR training system that immerses the user in a five minute simulation. The simulation is modelled after one of its aircraft hangars and allows engineers to participate in a fire evacuation (Goodwin, 2017). To enter the simulation, users put on a Samsung head-mounted headset connected to a mobile application, which shows them a 360 degree view of the hangar that reflects the same hangar set-up that the engineers operate in during their day-to-day work with their colleagues (Goodwin, 2017). An interviewed KLM representative highlighted that during the simulation, the user can make choices regarding how they respond at each stage and experience the impact of their decisions. The simulation is designed to give the user the information required without overloading the user with information, in order to encourage more active, inquisitive thinking, according to the same interviewee. For example, users can choose to fight the fire or escape in the simulated environment (Goodwin, 2017). Users are then awarded a star rating out of five points based on their decisions. According to an interviewed KLM representative, users repeat the programme until they obtain five stars.

Another interviewed KLM representative reported that initially, the VR training system experienced technical issues, such as faulty hardware or issues regarding software updates to the headset or phone. According to the same interviewee, this resulted in technical difficulties in the connections between KLM's training programme and the devices. However, another interviewee stated that these issues have now been addressed.

One major advantage of the system that the same interviewee perceived is the ability to manipulate the environmental factors and characters in the training simulation, which allows trainers to design more effective training systems.

Illustrations of potential socioeconomic implications: KLM's in-house research found that the VR training achieves improved knowledge retention. An interviewed KM representative reported that one advantage of the VR training system as opposed to the traditional classroom method is that the employee is more engaged through the game-like conditions and the storyline of the training simulation. The immersion of the user in a storyline can contribute to a potentially emotional experience, as some users expressed through a questionnaire (Goodwin, 2017). According to the interview with a KLM representative, users report that they benefit from the realism and 'fun' factor of entering the simulation, and the 'entertaining' aspect of the training is also designed to encourage repetition of the training. One KLM trainer interviewed also reported that the trainers have a positive view of the VR training tool due to the enthusiasm that trainees adopt in the learning environment.

Moreover, according to an interviewed KLM representative, the immersive experience means that the user is prevented from distractions caused by the sounds and movements of the real world, which could contribute to improved learning outcomes. As per the same interviewee, through improved knowledge retention, KLM's VR training is claimed to contribute to improved worker health and safety throughout the organisation.

[19] The study team interviewed two representatives of KLM

According to an interviewed KLM representative, the company saved on costs by shifting from the classroom to a VR-based training system. The same interviewee reported that the cost of vacating a hangar in order to implement a training session was very high in the classroom-style method, as the production processes were forced to stop; in addition, real-life, simulated trainings involved taking personnel out of their daily routine, as well as the involvement of the fire department. The VR training system also allows for quicker training completion for the workforce working in hangars. Due to the half-day duration of the classroom training, it could take one year for the organisation to implement the training for all of its engineers (Goodwin, 2017). Since the VR training only lasts 10 minutes, KLM is able to implement the training for all of its engineers at a quicker rate (Goodwin, 2017). According to an interviewed KLM representative,, staff members are able to conduct the training as and when required and at the discretion of the trainee. As highlighted by the same interviewee, the VR training system requires very little space in comparison with the classroom-style, And 35-60 people are reported to undertake the training each month.

The trainer’s role is changing to a coaching and mentoring role, which allows more attention for the individual, and could involve tailoring VR training to individual needs. According to an interviewee, KLM claims that no jobs have been lost due to the shift from classroom to VR training. Another interviewed KLM representative stated that they did not anticipate a need for new skills; however, trainers typically have to learn the skills required to operate the new technology.

KLM uses aggregated results data from its VR training system to improve training processes. The company regularly gathers information, such as training completion times and other general feedback (Koomen, 2018). However, an interviewed KLM representative mentioned that the company seeks to prevent discrimination against employees by not attributing the data to individuals.

Very few individuals experienced simulator sickness due to the virtual environment, dizziness or nausea and the training duration was reduced and signs of simulator sickness were reduced after the second trial (Koomen, 2018).

According to an interview with a KLM representative, the VR training system could also be contributing to improved employer-employee relations as users view the organisation’s considerable investment in new technology to improve the skills of its personnel in a positive manner.

In the future, KLM is considering expanding the use of VR training for other operational areas. KLM has already initiated a new VR training system for cabin crew and has trialled the system for cleaning training, as one interviewed KLM representative reported. KLM is also exploring using VR training for qualifications for pilots in difficult airports and for crew resource management.

KLM anticipates more demand in such jobs as internal software developers and it anticipates the roles of trainers to change. According to an interviewed KLM representative, the development of the VR training software has been moved from outsourced to internal capabilities, which created a demand for developers’ skills.

Table 6: Case example 3: Augmented and mediated reality in the Dutch National Police Corps

Augmented and mediated reality in the Dutch National Police Corps
Location: the Netherlands
Example service sector(s) the case example applies to: • Security and investigation activities (NACE sector N); • Public order and safety activities (NACE sector O).
Background and overview of technology: The digitalisation of crime scene data to support investigation is a costly endeavour in terms of required time and expertise (Poelman et al, 2012). The Netherlands Forensic Institute and the Dutch police initiated a pilot of a mediated-reality system (in this context mediation refers to the use of audio communications to communicate expert instructions to the officers on the ground) that facilitates collaborative crime scene investigation between crime scene investigators on-site and expert colleagues located remotely (Poelman et al, 2012). According an interviewed Dutch police representative, the impetus behind the initiative was to address such issues as the limitations of exchange of information through word of mouth alone during complex operations. Initially, the Dutch police trialled phones to communicate instructions in real time, instead of AR headsets, but informal feedback from police officers indicated that the use of phones did not aid the process sufficiently, according to the same interviewee. To develop the AR system, the researchers consulted five international experts in the area of 3D crime scene reconstruction to define the requirements for the mediated-reality system, which included processes to ensure that the crime scene remains as untouched as possible; remote collaboration with experts, who are a scarce resource; hands-free operation to free investigators' hands; and a lightweight, head-mounted display (Poelman et al, 2012). The system was then used in a staged crime scene at the Netherlands Forensic Institute training lab, which is designed to train investigators in realistic scenarios (Poelman et al, 2012). During the experiment, investigators with no familiarity with the mediated-reality system were tasked with tagging a crime scene, using barrier tape to demarcate the body in the crime scene, and conducting a bullet trajectory analysis (Poelman et al, 2012). The investigators then evaluated the use of mediated reality during the scenario. During the second pilot study, the Netherlands Forensic Institute, the Dutch police and the fire brigade of the Port of Rotterdam tested an AR system designed to support team collaboration through information exchanges and improve situational awareness (Lukosch et al, 2015). During a half-day workshop involving 12 members of various operations units, participants carried out various scenarios, including VIP protection, forensic investigation and responding to a domestic violence incident.
Illustrations of potential socioeconomic implications: The criminal investigators who trialled the mediated system found that it was feasible for the mediated-reality criminal investigation system to improve remote team collaboration through AR-facilitated visual communication combined with audio communication between on-site investigators and remotely located experts (Poelman et al, 2012). Team members reported that the visually oriented information exchange, which allowed team members to provide indications - such as 'behind the table,' 'don't cross the uttermost right ribbon,' and 'if you look slightly to the left' - facilitated joint-problem solving while team members were in dispersed locations (Poelman et al, 2012). Visual feedback on the spatial analysis was also reported by investigators to

support consensus building (Poelman et al, 2012). Another participant noted that having the same visual focus effectively aligned the cooperative effort of the on-site investigator and the remotely situated expert (Poelman et al, 2012). In the AR system, the quality of information was seen to increase, and the majority of participants reported that they found that the technology brought added value (Lukosch et al, 2015). One participant also mentioned that situational awareness of the criminal investigation process improved the sense that individuals were able to see their own role in the process as a whole and that the consequences of their work were more pronounced (Lukosch et al, 2015).

At the same time, according to the interviewed Dutch police representative, police officers reported that, due to limitations - such as the short battery life, unreliability and heavy weight of devices - the AR system did not meet the technical requirements for widespread deployment.

The mediated-reality criminal investigation system was also reported to reduce the time consumed by 3D reconstructions of crime scenes (Poelman et al, 2012). The system could lead to enhanced decision-making processes during court cases if evidence is available for the judge to view as soon as data are available (Poelman et al, 2012).

the interviewed Dutch police force representative noted that the on-site investigators were concerned about the potential for the mediated-reality system to intrude on their privacy, including the possibility that the data captured by the mediated-reality system (including potential errors in evidence collection) could be used to hinder criminal prosecutions (Poelman et al, 2012). On-site participants of the study expressed discomfort over the feeling of being observed through the mediated-reality system (Poelman et al, 2012). Simultaneously, police officers were more amenable to try the devices if the reasons for implementation and their concerns were discussed openly, according to the same interviewee.

Another likely impact in the long term that emerged from the second study was the potential for investigators to lose the skill to gather the ‘bigger picture’ of the scene due to AR’s tendency to make the user focus on the details of the crime scene (Lukosch et al, 2015). In addition, the interviewed Dutch police representative signalled the potential risk of deskilling of investigators in the long term if they become accustomed to passively receive instructions, rather than continuing to exercise creative thinking and problem-solving skills. Due to the prescriptiveness of task distribution through AR, responsibility could be taken away from the on-site investigator, and there is a consequential risk that accountability for errors or mishandling of crime scene evidence could become more ambiguous and harm due process.

In addition, interviewees[20] pointed to the potential demand for new roles, such as data managers, with responsibility for managing, modelling and visualising the data. The large volumes of data generated by interconnected devices, such as the AR system trialled, are increasingly generating a requirement for personnel with digital skills, according to the interview with a Dutch police representative.

[20] Based on separate interviews with a Dutch police representative and a European academic expert

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Annex – Further details about the research approach

Phase 1: Scoping phase

As noted in Chapter 1, the main objective of this phase was to validate the five technology areas to focus the study around and to examine the extent to which the technology areas originally identified by Eurofound (that is, advanced robotics, autonomous transport devices, blockchain, virtual and augmented reality, and wearable devices) remained relevant to the goals of this study. In addition, the study team aimed to ensure that other technologies with potentially cross-cutting impact on the five technology areas – such as artificial intelligence and data analytics – were also considered.

As part of the validation exercise, the study team surveyed white and grey literature,[21] including journalistic and blog sources, as well as company reports and individuals' websites focused on horizon scanning of science and technology. Key sources of literature targeted by the study team included reports by international organisations (for example, OECD, World Economic Forum and World Bank), documents from European Commission sources (for example, European Political Strategy Centre), industry sources (for example, McKinsey, Deloitte, and Accenture), academic literature (for example, *Harvard Business Review* and *MIT Technology Review*), and sources from think tanks or third-sector organisations (for example, Pew Research Centre, Lisbon Council, and Nesta). Many of these sources report on the deployment of emerging technologies and applications and thus enabled the study team to assess the current and emerging landscape of game-changing technologies in relation to the objectives of the study.[22]

The study team initially scanned these sources to identify specific citations of current and emerging technologies that are having/are likely to have a disruptive impact. The study team also identified some additional sources from the reference lists in the original corpus of articles. In total, 72 sources were identified to be examined through this quick scan of the literature. As part of the quick scan, the study team coalesced the identified technologies into broad technology area 'buckets' and conducted a 'strength of evidence' analysis of appearance of the technologies across the set of articles. This analysis assessed the frequency of the number of appearances of the technologies across the set of articles. Additionally, the nature of the evidence available (for example, peer-reviewed or grey literature) was also considered when determining the strength of evidence.[23]

Finally, having identified the technology areas, the study team discussed and validated the findings of the analysis with three 'cross-technology' experts. These scoping consultations focussed on establishing a cross-sectoral overview of the technology areas and their influence on key study themes, such as working conditions, employment prospects and productivity.

[21] 'White literature' refers to the content produced by commercial publishers. 'Grey literature' refers to content produced by entities (individuals or organisations) which do not publish content as their main task. For more details, see https://www.lib.uwo.ca/tutorials/greyliterature/

[22] Key search strings included the following terms and their combinations: 'game-changing technolog*', 'emerging technolog*', 'disruptive innovation', 'future of jobs', 'future of employment', 'future of work', 'future of productivity', 'new job skills for the future', 'future of workforce', 'future of services', 'future of services sector'. Additionally search strings related to specific service sectors – for example, transport, financial services, health and healthcare, retail, hospitality, logistics, pharmaceuticals, and entertainment – were used to augment the search as necessary.

[23] It is important to note that in the event of a consultation conducted with a wider set of stakeholder groups and a systematic review of the literature, the emerging strength of evidence could differ significantly.

Phase 2: Analysis and synthesis phase

Literature review searches

The study team identified a bibliography list for each of the technology areas. When the search was conducted, the emphasis was on articles that discuss the (potential) implications of the (future) technology applications in the services sector on the following aspects: work and employment (for example, in terms of skills and competences, working conditions, job quality, and employment relations) and production processes (for example, in relation to productivity, outputs, business models, and value chains). Although articles published before 2013 were considered where relevant, articles published from 2013 onwards have been prioritised. The study team focussed on building a corpus of English-language articles to inform the technology deep dives, but, where appropriate, a limited number of articles in other languages (for example, Dutch, French, German and Italian) were examined. Additional relevant articles were also 'snowballed' from the reference lists of some of the originally identified articles.

The generic search strings used for informing the initial literature search were as follows:

Generic search strings
([technology area] AND service*) AND (work* OR employment OR skill* OR productivity OR working conditions OR work* relation*)
([technology area] AND [specific service sector]) AND (work* OR employment OR skill* OR productivity OR working conditions OR work* relation*)

Exemplary search strings for the [technology areas] were as follows.

Technology area	**Search string**
Advanced robotics	(Advanced robotics OR mobile robotics OR robot*)
Autonomous transport devices	(Autonomous transport devices OR autonomous vehicles OR driverless cars OR drones OR autonomous transport*)
Blockchain	(Blockchain OR distributed ledger* OR dlt)
VR/AR	(Virtual reality OR augmented reality OR mixed reality OR immersive technolog*)
Wearables	(Wearables OR wearable* OR wearable technog* OR wearable device*)

Limitations of the analysis

There are some caveats that need to be borne in mind when reading and interpreting the analyses presented in this working paper. This working paper is part of a larger study that includes the five potentially game-changing technology areas: advanced robotics, autonomous transport devices, blockchain, virtual/augmented reality, and wearable devices. Where relevant and supported by the discussion in the underlying literature, the study team has considered cross-functional and cross-sectoral implications of these game-changing technologies on each other. However, this working paper is intended to be stand-alone, and thus the emphasis is on the trends and socioeconomic implications observed in relation to virtual/augmented reality.

During the scoping phase, additional technology areas – notably artificial intelligence and big data analytics – also emerged as important areas for consideration. However, the available literature suggests that these technology areas cover a broad spectrum of changes that could have a significantly transformative effect on the wider society and the economy. As a result, the study team has regarded these technology areas as 'transversal', or 'cross-cutting', and therefore to be considered in conjunction with the five core technology areas as needed – that is, whenever pertinent information about these technology areas emerged when the study team was collecting evidence, this was included in the analysis. For example, artificial intelligence appeared as a significant cross-cutting technology area that has been considered in the analyses conducted in relation to advanced robotics and autonomous transport devices. Any such discussion is informed by the relevance of these technologies within the key themes of this study and where supported by available evidence.

To identify the most relevant literature for the analysis, the study team adopted a rapid evidence review approach. Rapid evidence review does not aim for systematic coverage of the literature and thus aims to strike a balance between the available time and achieving sufficient depth of coverage in selecting the material. In doing so, the study team prioritised peer-reviewed literature for analysis. Grey literature was used to corroborate the findings, where relevant. Since the literature searches predominantly identified English language sources, where feasible the study team looked out for non-English material. Although the study team aimed to ensure inclusion of relevant material, it recognises that the rapid evidence review approach may result in important material not being identified in some cases.

For the interviews, the study team identified a long-list of experts drawing on its own network and subject matter expertise, and with inputs from its advisory board. A short-list was identified based on a consultation with Eurofound to ensure geographical coverage across Europe. The interviews were done based on availability of the external experts and to ensure a broad coverage of the themes related to the study. The study team has primarily used the expert opinion to complement findings from the evidence review. In some cases, expert testimony has been used to identify possible outcomes in the absence of suitable peer-reviewed material. In such instances, the study team has endeavoured to identify these outcomes as expert opinions rather than corroborated facts.

These game-changing technologies are still in the early stages of development, and their implications are still emerging. Therefore the discussion in this working paper combines qualitative analysis with quantitative data where available. Since long-term data on the adoption of technologies is not yet readily available, the study team has considered the available data in the form of patents, research publications, and R&D expenditure as signals of market interest and activity. To understand the general trends across the EU and in key non-EU countries, such as the USA, Japan and China, the study team referred to the latest available Eurostat data on patent activity and R&D expenditure. The timelines for this Eurostat data vary: the latest data on R&D expenditure is dated 2016, and the latest patent data on high-tech sectors is dated 2013. The study team acknowledges that some of the trends observed in the study may change significantly once newer data sets on patents or R&D expenditure become available.

For analysing the trends specific to the technology areas, the study team used the patent landscape reports available via the World Intellectual Property Organization's (WIPO) website[24] and the data on patents and research publications published by the Tools for

[24] See http://www.wipo.int/patentscope/en/programs/patent_landscapes/ for more details.

Innovation Monitoring (TIM),[25] created by the European Commission's Joint Research Centre (JRC). With both these sources, the study team did not have access to the underlying data, and thus the findings on patent data and research publications in relation to the technology areas presented in the study are a form of secondary analysis. Some patent landscape reports rely on the patent data available in public domain and thus do not incorporate the findings for the latest five years at the time of their publication. Although the study team endeavoured to ensure that latest patent landscape reports were referred to for each of the technology areas, as of 2018, some of the reports only cover the patent data until 2013. Additionally, the study team recognises that although the patents, publications and R&D expenditure data are useful to identify macro-level trends, these data do not provide the full picture of trends regarding the development and adoption of the technologies. This analysis is thus intended to inform the analysis of socioeconomic implications in relation to such themes as work, employment and productivity, rather than provide a definitive account of the potential outcomes of these technology areas on the services sectors in Europe.

Although the study team has, as far as possible, endeavoured to adopt a pan-European perspective in the analyses, it is important to acknowledge that the geographic scope within Europe in relation to data gathering for the study has been underpinned by the technologies themselves.

[25] See http://www.timanalytics.eu/ for more details.

Protocol for stakeholder interviews

Part 1: Introductory Questions

1. What is your current role and background?
    - For what areas do you have responsibility?
    - Do you have any conflict of interest in relation to this study?

Part 2: General understanding of the developments in the [technology area] landscape

2. With regard to the current state of play of [technology area] (in Europe and beyond), what do you think are some of the main trends that we observe?
3. What are some of the important driving forces for these trends that are enabling the development and adoption of [technology area], and why are these important?
4. What are some of the potential barriers to the development and adoption of [technology area], and how are they hindering the progression?

Part 3: Perceptions of the different socioeconomic implications of [technology area]

5. In relation to its potential to be a ‘game-changing’ technology area, how are [technology area] likely to have implications for the services sector?
    - In your view, which service sectors (and subsectors or specific industries) do you think present the current (and future) opportunities for the application of [technology area], and why?
    - Can you provide examples of applications of [technology area] in these sectors?
    - Aligned with the earlier question, in your view, which service sectors are least likely to be influenced by the development and adoption of [technology area], and why?
6. We would like to discuss the qualitative implications (positive and negative, direct and indirect) of [technology area] in terms of the following broader themes:
    - Work organisation, (workforce) productivity, and output/products
    - Employment
    - Skills
    - Individual working conditions
    - Collective employment relations
    - Are there any other implications?

Part 4: Perceptions of potential applicability of [technology area] to services sectors in Europe and beyond

7. In relation to some of the points that that you have raised so far, could you offer any observations that are specific to EU countries, or particular “geographical areas” in Europe?
    - How does the situation vary in / compare to different parts of the world?
8. More specifically, do you have any thoughts on potential ‘real world’ case examples to illustrate the application/implications of [technology area] in particular services sectors?
9. Could you recommend any relevant literature sources that we should consult as part of this study?
10. Do you have any thoughts on prospective quantitative data sources/indicators that we could draw upon?

Part 5: Additional insights – ethics and collective bargaining

11. Do you have any thoughts about the ethical implications concerning the deployment of [technology area]? Do you have any thoughts on the way increased use of [technology area] could change or influence the ethics of human-machine interaction at work would be welcome.

12. Do you have any thoughts about developments, if any, in collective bargaining with regard to changes in job descriptions or occupations?

Part 6: Wrap-up

13. Do you have any recommendations for other potential (technology/socioeconomic) experts and/or stakeholders that you think we should be speaking to?
14. Do you have any recommendations for potential case examples i.e. examples of [technology area] being used in practice and showcasing some of the implications we have covered as part of this discussion?
15. Based on your knowledge and experience of working in this field, is there anything else that you would like to add that we have not yet covered?

Interviewees

- Industry expert
- European academic expert
- European researcher
- European academic expert

Case example interviewees

- DHL representative
- Two representatives from KLM
- Dutch police representative

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency established in 1975. Its role is to provide knowledge in the area of social, employment and work-related policies according to Regulation (EU) 2019/127.