XR

and its potential for Europe

Brussels, April 2021

ECORYS

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Ecorys is an economic and strategy consulting firm with a global reach, serving clients in over 100 countries. The company's history dates back to 1929. Ecorys Brussels serves as a focal point for the company in delivering services to clients at European Institutions and tech companies.

Opinions or conclusions expressed in this report represent a consensus of the authors based upon extensive qualitative and quantitative research and do not necessarily represent the official position of the actors of the XR industry.

Contents

Acronyms

2D	Two-dimensional
3D	Three-dimensional
AI	Artificial intelligence
AR	Augmented reality
AV	Augmented virtuality
CEF	Connecting Europe Facility
CEO	Chief Executive Officer
CO2	Carbon dioxide
DIH	Digital innovation hub
EFSI	European Fund for Strategic Investments
ESIF	European Structural and Investment Funds
EU	European Union
GPS	Global positioning system
H2020	Horizon 2020
HMD	Head-mounted display
HUD	Head-up display
ICT	Information and communications technology
IoT	Internet of Things
ML	Machine learning
MR	Mixed reality
NACE	Statistical classification of economic activities in the European Community (Nomenclature statistique des activités économiques dans la Communauté européenne)
RV	Reality-virtuality (continuum)
SLAM	Simultaneous localisation and mapping
SME	Small and medium-sized enterprises
SWOT	Strengths weaknesses opportunities threats (analysis)
UI	User interface
UK	United Kingdom
US	United States
UX	User experience
VR	Virtual reality

Foreword

We are poised on the precipice of an immersive future. Virtual, augmented and mixed reality technology (XR) will fundamentally change how we connect, communicate, collaborate and learn. The COVID-19 pandemic accelerated trends in digitisation broadly, and there is a clear path towards XR as the next computing platform. The seeds of expansion in XR are evident throughout Europe, and we are honoured to partner with Ecorys again to provide valuable data and insights around the European experience with immersive technology.

Four years on from our first report on the state of play of the AR, VR and MR industry in Europe, we see that the cultural diversity, creativity and the long arc of commitment to research and development in Europe continues, and is generating strong signs of growth.

While this report provides unique insights into the size and market value of the industry, as well as the unique ways in which different countries and European regions contribute to the growth of XR, we also wanted to highlight the ways in which XR fuels some of the leading priorities of the European Community. Its contribution to sustainability and job growth shows great potential, and the efficiencies and tools of collaboration that XR present fit the emphasis on digitising the European economy.

We hope that this report will show industry players opportunities for growth, that enterprise companies will consider how XR can help to achieve broad corporate goals, that consumers will better visualise an immersive future, and that governments will identify ways in which specific support for XR technologies can lead to broader adoption and desired policy results. Our mission at XRA is to support responsible development of XR that will lead to positive societal outcomes. To do so, we must be clear-eyed about the opportunities and complexities that XR presents. This report is the latest 'data point' in the pursuit of that goal.

Elizabeth Hyman
President and CEO of the XR Association

XR ASSOCIATION

Preface

XR is a set of technologies that is proving its potential to transform the way we live and do business. Since Ecorys' 2016 study, 'Virtual reality and its potential for Europe' (referred to in the text as 'Ecorys' VR 2016 report'), new developments have shaped the evolution of the XR industry. Advanced hardware has become available and new start-ups and innovative projects have emerged, further stimulating demand for XR applications. In this context, the European XR industry has been growing in terms of the number of companies, turnover, employment and value added.

This report details potential developments in the European XR industry. There has been strong European Commission support in the context of the 'A Europe fit for the digital age' priority, and the associated initiatives and funding opportunities available for new and advanced technologies in Europe.

The year this report was prepared in (2020) was shaped by the COVID-19 pandemic, which negatively impacted the global health and economy, but also gave digital transformation a boost in industries requiring innovative solutions for remote collaboration and digital online interaction (amongst other things), areas which can be addressed with XR solutions.

In this updated and upgraded version of Ecorys' VR 2016 report, we present an introduction to XR and its technological progress (Chapter 1), an overview of the quantified XR industry trends in Europe (Chapter 2), and an analysis of different aspects of the dynamic XR ecosystem through a European XR mapping exercise (Chapter 3). Chapter 4 ('XR and the digital transformation of Europe'), Chapter 5 ('XR meets environmental sustainability') and Chapter 6 ('A fast-growing need for XR jobs and skills') act as thematic 'deep dives' linked to key EU policy priorities.

The study concludes with an overview of where the industry currently stands and highlights potential areas for future improvement (Chapter 7).

1 XR and its technological progress

The rise of XR technology in recent years is the result of over a century of research and development – more than most people imagine.

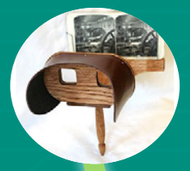
XR research and development in Europe has been incredibly broad, ranging from hardware components (i.e. sensors) to advanced manufacturing techniques including AI and ML. In terms of thematic areas, developments can be seen in all sectors, from healthcare to manufacturing and education.

XR is an umbrella term describing an existing set of immersive technologies which enhance reality and our senses by adding digital information to the real world or creating a new digital environment altogether, as well as future immersive technologies. A detailed overview of the definitions and characteristics of the three main XR technologies virtual reality (VR), Augmented Reality (AR) and Mixed Reality (MR) are available in Annex I – Understanding XR.

XR technologies have only recently become better known to the wider public as they are becoming more mainstream only now, but the current breakthrough in hardware and software has been based on several years of research and technological progress.

Timeline of key milestones in the development of the technologies

The birth of XR technologies can be traced back to 1838, when Charles Wheatstone invented the stereoscope. The device created 3D images starting from their 2D version and paved the way for additional breakthroughs in the late 19th century and early 20th century, mostly focusing on optics and lenses creating immersive images.



1838
Stereoscope

1968
Sword of Damocles (VR)

1962
Sensorama (VR)

1974
Videoplace (AR)

1977
Sayre Glove (first glove)

Throughout the 20th century, primitive forms of head-mounted displays (HMDs) and visors started to appear, together with devices designed to involve senses other than sight; these were mostly touch and hearing. The first prototypes of gloves appeared, together with the first immersive room, in the early 90s.

1982
Power Glove and Dataglove

1986
Air Force Super Cockpit Program (VR)

2014
Google Cardboard (AR)

2014
Oculus acquired by Facebook

1988
Virtual Interface Environment Workstation (VR)

1995
Nintendo Virtual Boy (VR)

1992
Virtual Fixtures (AR)

1991
Virtuality (VR)

1997
VR used for PTSD therapy

While most of the technologies developed so far fell under the modern definition of VR, there were attempts to augment the real world instead of simulating it. AR developments were fostered by the creation of ARToolKit, software which can capture real-world actions and combine them with interactions with virtual objects. This was the base for the first Web-based XR applications.

2000
ARToolKit developed in Japan (AR)

2001
SAS cube, first PC-based cubic room

2012
Kickstarter campaign for Rift

2010
first Oculus Rift prototype

2007
Google announced Street View (AR)

2013
Google Glass (AR)

The late 2000s to the early 2010s saw XR headsets become more developed, comfortable and affordable. Interest in XR started to grow thanks to the many enterprise applications and to the global uptake of smartphones. AR also started to become more mainstream.

2016
HTC Vive (VR)

2016
Oculus Rift (VR)

2016
Microsoft HoloLens (MR)

2016
Playstation VR (VR)

2016
Pokémon! Go released (AR)

2018
Magic Leap One (MR)

2019
Hololens 2 (MR/AR)

2020-2025
Apple is expected to release its own VR/AR headset

Thanks to increasing market demand, more and more tech giants investing in XR and a buzzy start-up industrial landscape, we can only predict that technology will continue to develop with more improved devices, technologies and applications in the coming years.

2 The growing European XR industry

The European XR industry has demonstrated resilience during the COVID-19 pandemic. Given its potential to provide solutions to several issues caused by this crisis and despite a short-term slowdown, its growth rates are expected to increase and eventually surpass the pre-COVID-19 estimates.

The European XR industry is expected to reach between €35 billion and €65 billion by 2025, representing a gross added value of between €20 billion and €40 billion, and directly creating employment for up to 860,000 people.

2.1 The increasing relevance of XR

The European XR market has matured over the course of the last few years. Surrounded by excessive hype in the past, it has been expanding relatively slower than foreseen in the previous estimates of Ecorys' VR 2016 report, but nonetheless is steadily growing, and this is expected to continue. There are several reasons behind the continued importance and growth of this technology. Our research finds that 2020 provides fertile ground for the further growth of XR technology in Europe. Three key trends are behind this:

1| A globally expanding XR industry and market

One of the main drivers lies in the increased relevance of XR for enterprise applications. This is caused by two key correlated factors. The first is the availability of better XR technologies, such as comfortable, powerful and custom-tailored headsets for enterprise. The second is the generally higher demand for enterprise XR solutions from companies interested in digitalising part of their work processes. This is leading to increasing investments, especially from big companies, some of which are starting to implement XR into their workflows[1]. Companies are acknowledging the gains, in terms of the time and money saved by immersive technologies, in many industrial, business and educational processes.

XR for private use such as gaming and home entertainment remains a steadily increasing market as well, with new software and applications coming to the market regularly. Niche XR applications and use cases, such as the use of XR for sustainability purposes, are also starting to appear, with high potential for future growth, given the attention drawn to the greening of the economy.

2| An urgent need for solutions offered by XR applications

There are potential impacts on future developments relating to the COVID-19 pandemic. In the overall economy, investments and revenues have been negatively impacted. XR is experiencing the consequences of the general economic shock, but there are reasons to consider that the XR market may be more resilient than others, and that the shock concerning it will only be short term. This is due to both the societal/technological consequences of the pandemic and the intrinsic characteristics of XR technologies.

The COVID-19 pandemic has prompted companies to accelerate their digital transformation and is arguably set to lead to a general upskilling and familiarisation across

1 E.g. Audi, DHL, Airbus, etc.

society with regards to generic digital skills, increasing the pool of potential buyers and consumers of XR content. The XR industry can also offer solutions for addressing challenges imposed by the pandemic, and the ways it will change the way we work, live and interact with each other, for instance an increased demand for remote and digital products for both private (as an entertainment, as well as communication and education tool) and professional (providing key solutions for the future of work through remote collaboration applications and digitalising work processes) use.

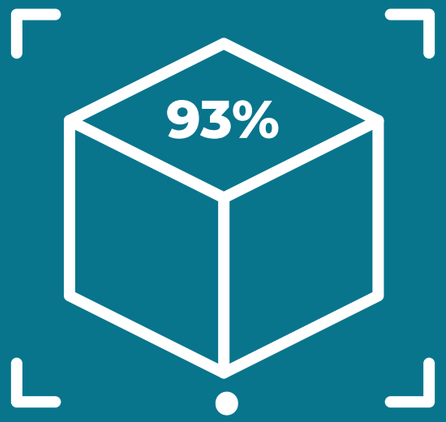
3| A boost by political priorities and policies

Digitalisation is a ubiquitous trend affecting most organisations and authorities. Within the EU, the European Commission supports the digital transformation of the industries on the continent through its 'A Europe fit for the digital age' political priority, one of its most prominent, together with the sustainability efforts embodied by 'A European Green Deal'. Digitalising working processes has the potential to make European companies more competitive and open up new markets, focused on cutting-edge technologies.

A number of policy initiatives and funding opportunities are supporting this trend by investing in new technologies, ensuring that infrastructure (e.g. 5G networks) is in a good position to make the most of these technologies, and by creating a legislative framework (e.g. regarding data protection) affecting new technologies.

2.2 XR in Europe 2020-2025

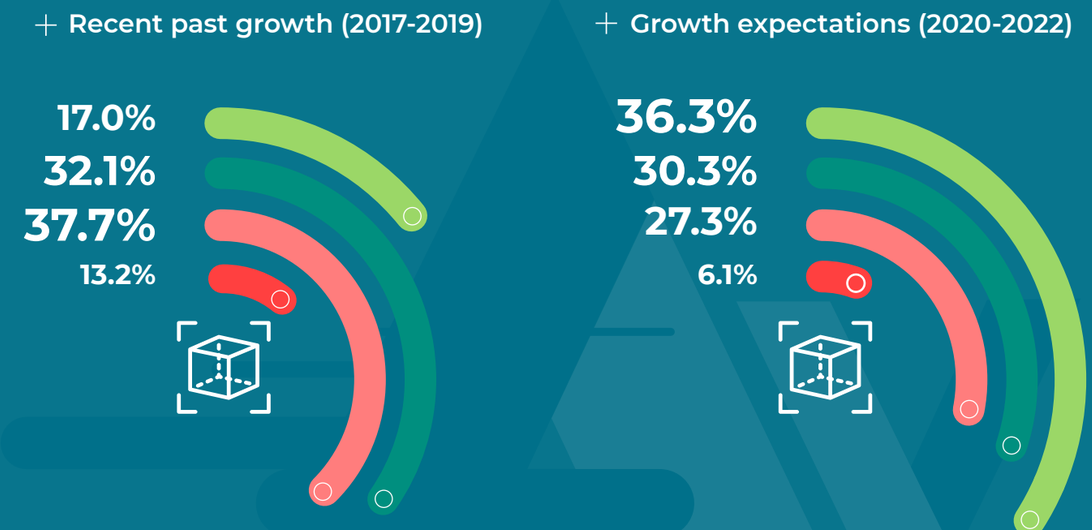
Recent trends and expectations for the future suggest that VR and AR companies in Europe are growing at a sustained rate. Over 86% of consulted companies state that they have expanded their XR sales and turnover during the past three years, and for roughly 50% this growth was substantial (from 50% up to 150%). Looking ahead, over 93% of consulted companies foresee growth in their sales and turnover during the next three years, with two thirds expecting their revenues to grow by more than half (and in some cases, to more than double). To put this number in perspective, it is important to note that over 80% of respondents to the Ecorys XR industry survey represented companies with fewer than 50 employees (see methodological note in Annex II for additional details on sample composition).



3 years

Over 93% of XR companies expect their sales and turnover to grow in the next three years

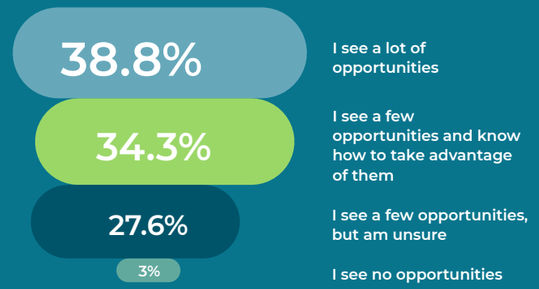
European XR companies' recent sales and expectations for turnover growth



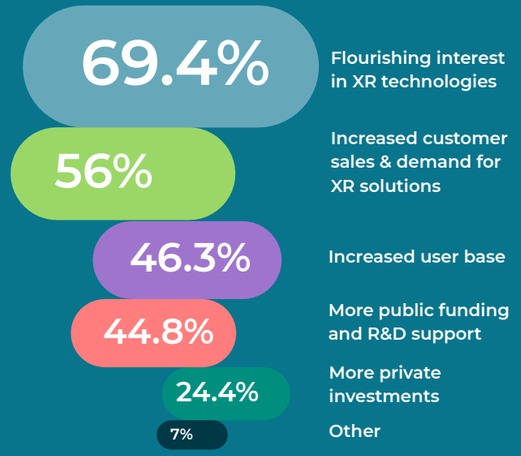
Negative Growth | Moderate Growth (0-50%) | Med-High Growth (50-150%) | Exponential Growth (>150%)

Source: Ecorys (2020), *XR Industry Survey*, see methodological note in Annex II.

Do you see any new opportunities for XR technologies as a result of the COVID-19 crisis?



Which of the following opportunities do you expect to have an impact on the XR market?



Source: XR4ALL (2020), COVID-19 Survey: Impact on XR in Europe

Although the consultation was carried out during the COVID-19 pandemic, hence partially internalising the pandemic's impacts, the future net effects on the XR market are not straightforward and easy to predict. A consensus on this seems out of reach within the XR community at present, due to the different impacts of COVID-19 on various XR-related business models and solutions[2], and different views on the timeframe of the recovery. There is, however, widespread confidence in the ability of the industry to smoothly bounce back after an inevitable short-term hit and slowdown, with some technologies even benefiting in the long term. This will depend on the developments related to the pandemic and overall macroeconomic conditions, which are hardly predictable at this stage, but also on the ability of the industry to keep up the momentum and grasp the opportunities emerging in specific XR applications, such as remote collaboration and digital online interaction.

To determine the impact of the growing demand for XR on the European economy over the next five years, we have assessed the current and future size of the European XR industry. This is based on analysis of different market studies, considering the specific characteristics of the European industry and possible impacts of the COVID-19 pandemic. Our assessment is complemented by insights collected via companies and expert consultations. We estimate that the European XR industry will generate about **€8 billion revenue in 2020**.

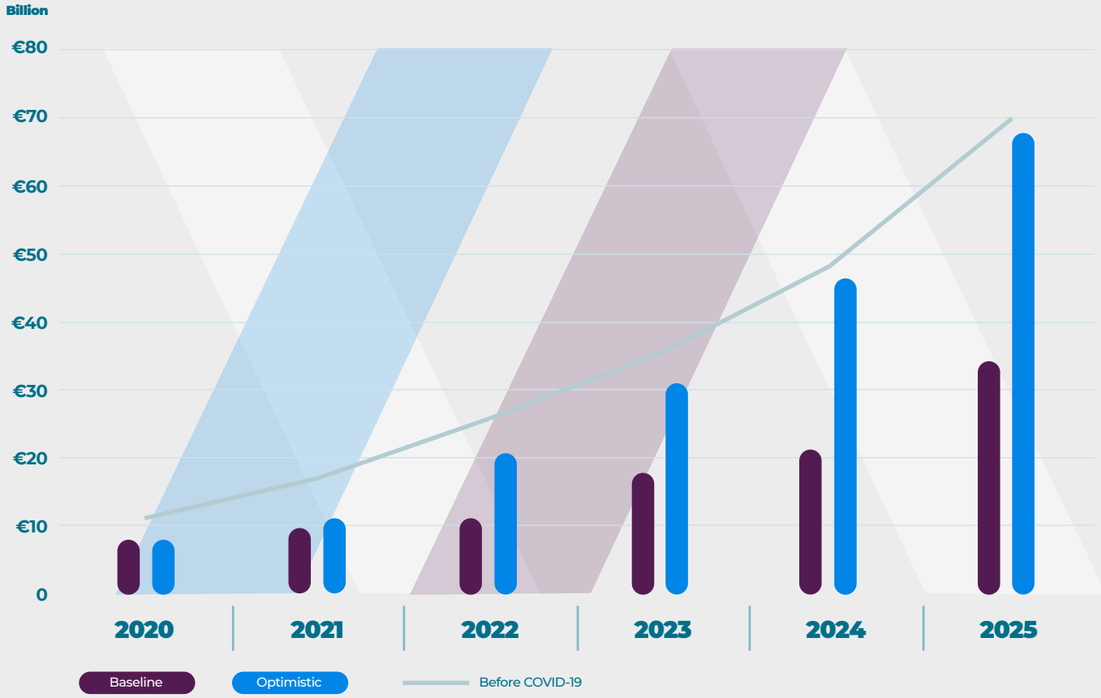
The forecasts until 2025 are based on two scenarios, with the same starting point, that consider different parameters and potential future developments, such as investments by major technology firms leading to innovation, and the net effects of the current pandemic on the European XR industry.

In the **baseline scenario**, we foresee a slowdown induced by the pandemic, with the XR industry experiencing a steady growth, but with lower growth rates than estimated before the pandemic. The industry is still expected to bounce back and approach pre-COVID-19 growth rates by 2024, boosted by a moderate growth of the mass market of consumer applications. The industry will then slowly get back on track to its organic demand and growth trend in line with the wider economic recovery.

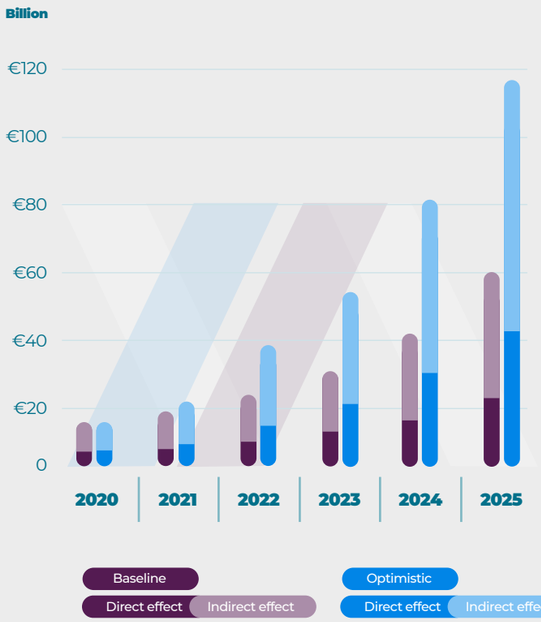
In the **optimistic scenario**, following a short-term setback, the XR industry is expected to have bounced back to (and even slightly surpassed) pre-COVID-19 growth rates by 2022, and approached pre-pandemic estimates in absolute terms by 2025, particularly boosted by growing applications such as remote collaboration and an increased demand for online digital interaction solutions. Optimal conditions exist for the growth of VR/AR that will stimulate the purchase of headsets by a wider number of consumers, induced by further advancements in (semi-)immersive experiences (e.g. better designed human-computer interactions and user interfaces, more user-friendly and comfortable hardware, software optimisation and higher performance), breakthrough consumer applications and creation of new content.

In these scenarios, the total market value of the European VR and AR industry is expected to increase to **between €35 billion and €65 billion by 2025**, representing a gross added value of between €20 billion and €40 billion, and directly creating employment for some 440,000 to 860,000 people. Wider supply chain impacts are also expected to indirectly increase production value to between €35 billion and €70 billion, generating an additional 780,000 to 1.5 million jobs.

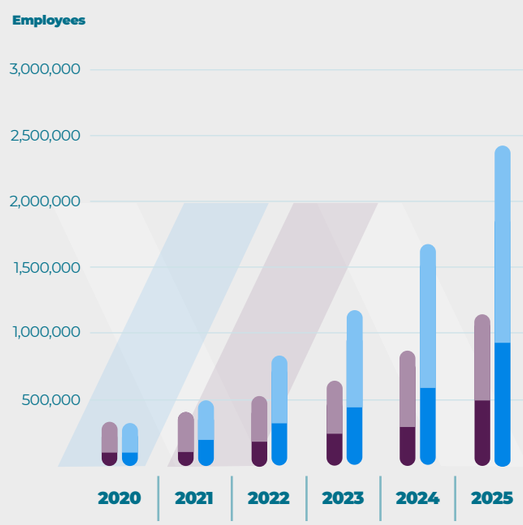
European XR market value €bn (2020-2025)



European XR value added €bn (2020-2025)

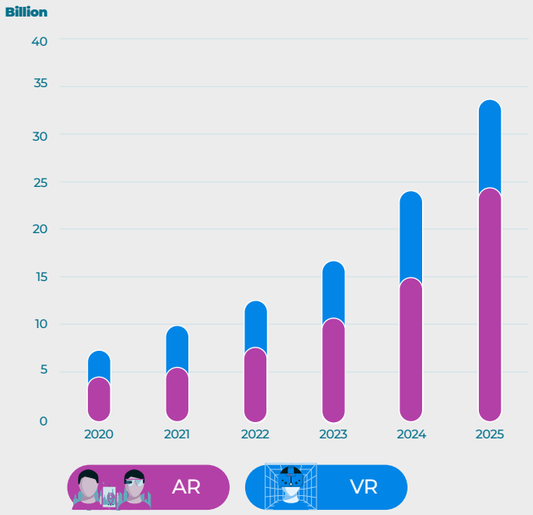


European XR employment (2020-2025)

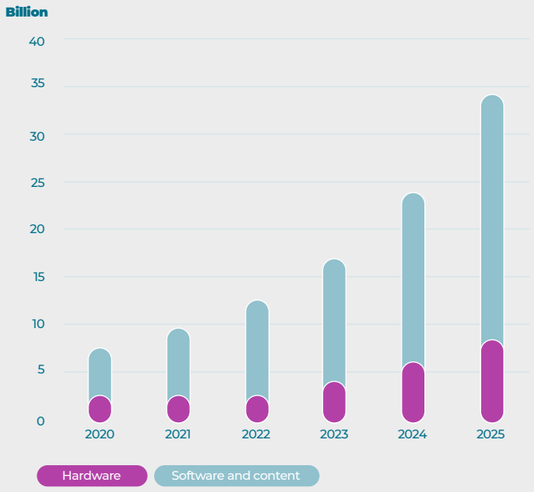


2 E.g. Location-based XR facilities suffer more than companies offering remote collaboration tools.

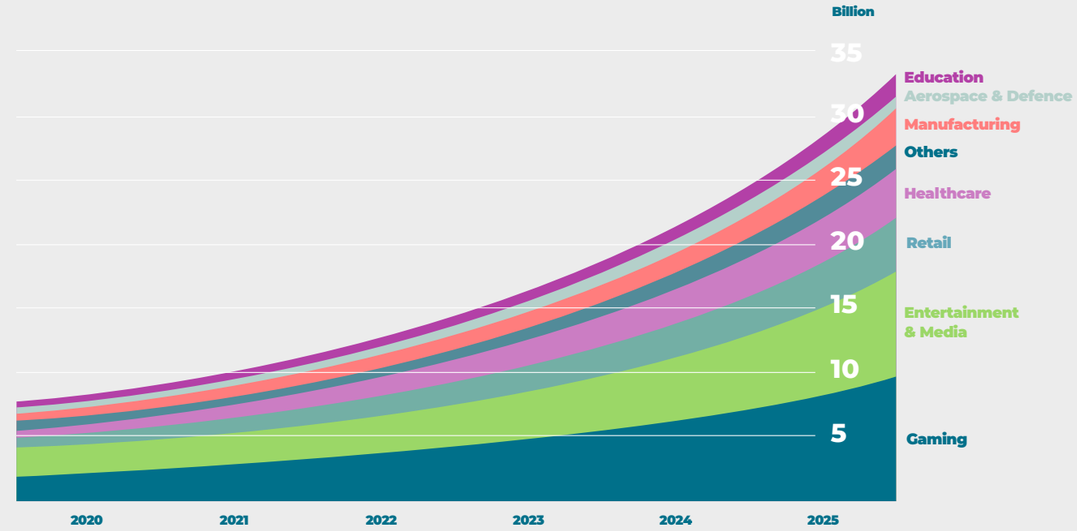
European XR market value (€bn) by technology (baseline scenario)



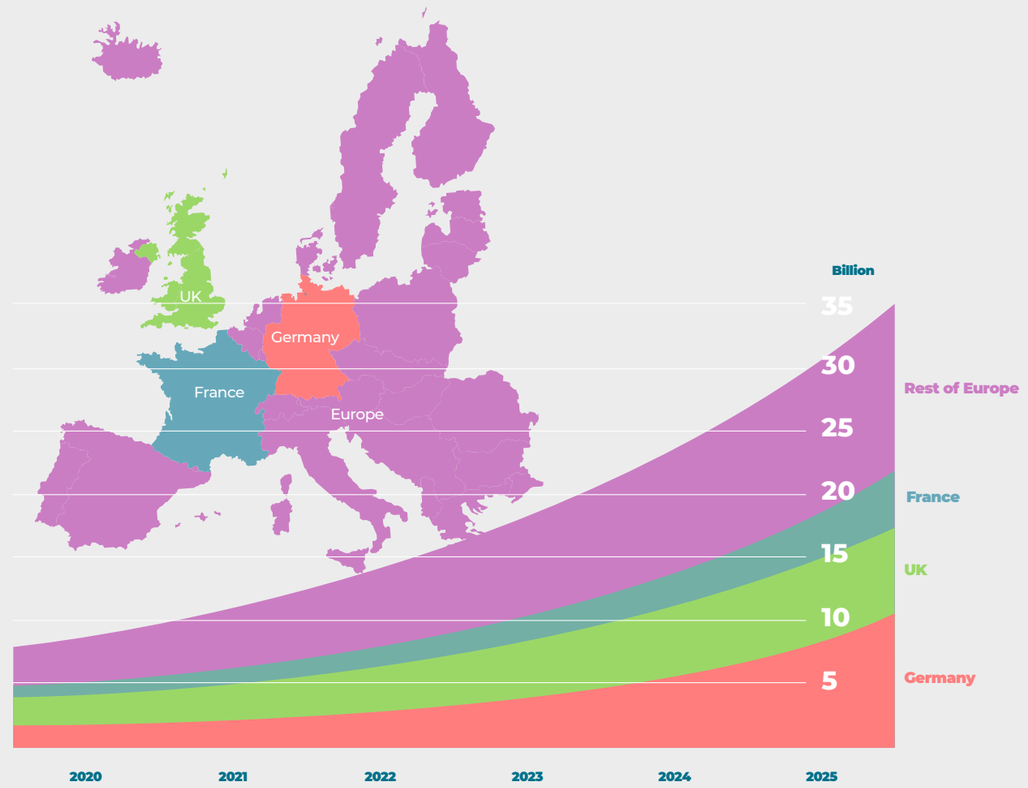
European XR market value (€bn) by component (baseline scenario)



European XR market value (€bn) by sector (baseline scenario)



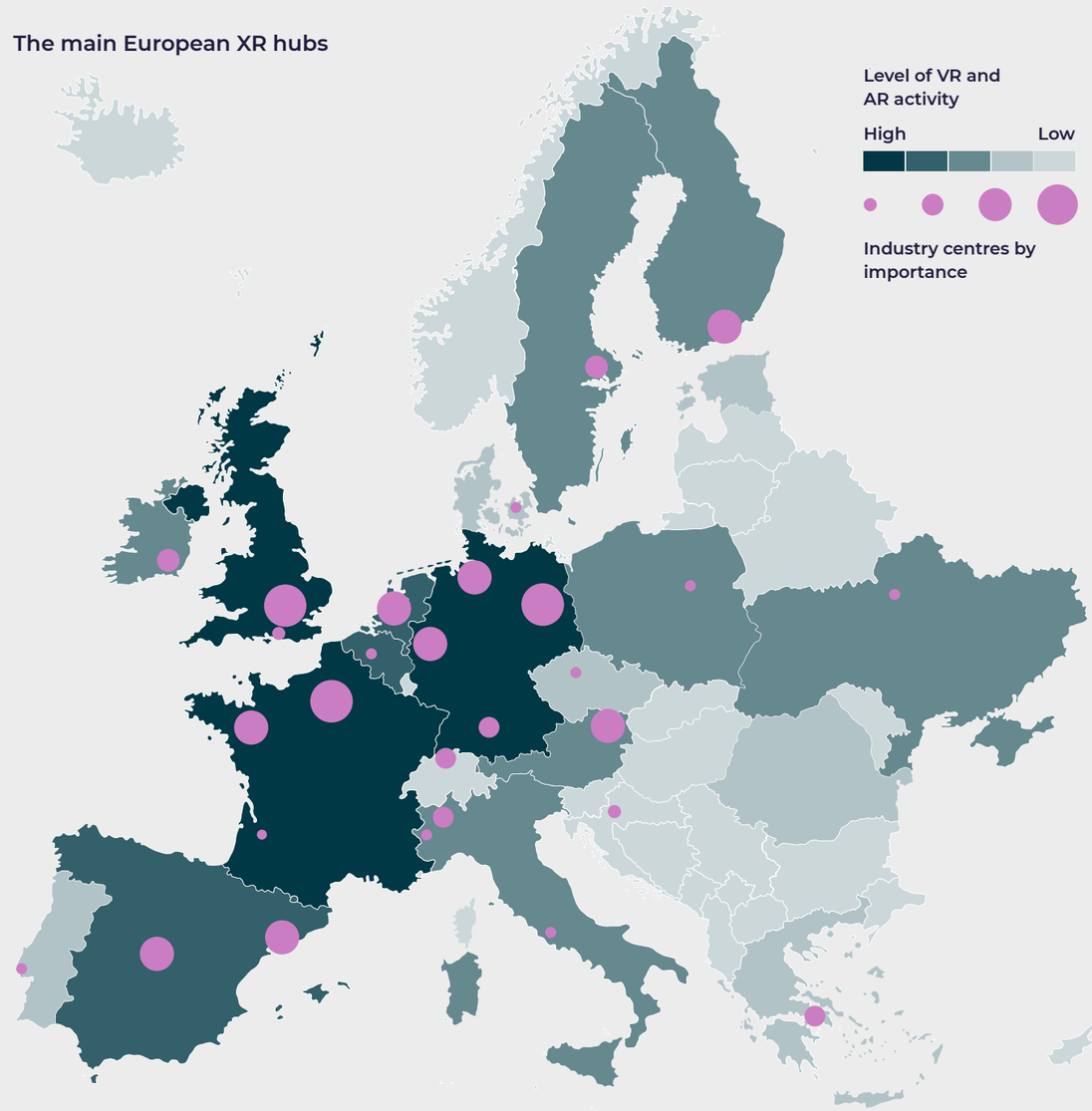
European XR market value (€bn) by country (baseline scenario)



3 The European XR ecosystem

The European XR ecosystem has been steadily evolving, with Germany, the United Kingdom (UK) and France being the strongest performers in terms of the number of XR companies and turnover generated by XR activities. Since Ecorys' VR 2016 report, the adoption of the European Digital Strategy has provided several opportunities from which the XR industry is benefiting. More initiatives specifically targeted at XR at national or local level have played an instrumental role in the development of XR hubs in Europe.

The main European XR hubs



Source: Ecorys XR industry database (2020), see methodological note in Annex II

The XR industry is distributed across several European countries and regional hubs. Over the past years the main hubs such as London, Paris, Berlin, Amsterdam, Zurich (already identified in Ecorys' VR 2016 report) have been maintaining and expanding their activities, in some cases building strong records in specific application areas or technological focus. Since Ecorys' VR 2016 report, the cities and surrounding areas of London, Berlin and Paris have further strengthened their leading position in terms of companies (including start-ups) focusing on or engaging in XR activities, with multiple additional hubs growing in importance in the context of the European XR mapping. In addition, the biggest European XR hubs are also accommodating some of the leading universities and research institutes in XR research and development.

While the focus of European XR industry is primarily related to software development and content creation, tailored hardware development maintains a higher-than-anticipated share of the market. Other actions supporting the XR industry also occupy parts of the industrial activity. In terms of thematic focus, Europe as a whole is equally strong in VR and AR applications across all sectors where XR applications exist globally, from gaming and entertainment to healthcare and manufacturing applications. In these sectors, XR can enhance and innovate the way things are done, for example by creating immersive video game and movie experiences, helping doctors to conduct remote surgeries, and facilitating work processes in a variety of ways in the industry (more on this in Chapter 4). This way, the European industry complements the global XR scene and is gaining a leading position in certain areas, for instance by producing creative content inspired by European cultural diversity for entertainment purposes, or innovative applications to meet the needs of the high-tech, highly specialised and advanced European industries. While gaming and entertainment applications are predominant within the EU ecosystem, industrial XR applications have been growing at a faster pace. In some cases, thematic specialisation is observed for each hub, linked with established industrial sectoral activities – healthcare XR applications in Zurich, for instance, or gaming in Stockholm and Helsinki.

On top of the global ecosystem and associations that support the XR industry (such as the Extended Reality Association[3]) and national-level organisations (presented below), the European XR ecosystem is reinforced by European-level associations, events and initiatives that bring the XR industry together. Notably, the EuroXR[4] Association brings together national associations, as well as individual members and companies interested in XR. Their annual conference has brought together research, industry and commerce representatives from across Europe since 2010, and was held for the first time virtually in 2020. Since Ecorys' VR 2016 report, new cross-border initiatives have emerged and are active at European level. For instance, since 2018, the EU-funded initiative, XR4ALL[5], has played a significant role in creating an online community for exchange on XR, providing financial support for the development of XR solutions and identifying research priorities in XR. Almost 1,000 experts, researchers, developers, creatives, start-up founders and industrial representatives are part of the XR4ALL community. A network has thus been created, allowing European regional associations to join forces in XR community building. Other initiatives that have increased their presence and activities include the Women in Immersive Tech[6] and the Extended Reality for Education and Research in Academia (XR ERA)[7] with a focus on education aspects.

3 The XRA
4 EuroXR
5 XR4ALL
6 Women in immersive tech
7 XR ERA

XR research and development in Europe has been incredibly broad, ranging from hardware components (i.e. sensors) to advanced manufacturing techniques including AI and ML. In terms of thematic areas, developments can be seen in any sector, from healthcare to manufacturing and education. However, there are limited funding and support opportunities dedicated to XR at EU level. Some projects are finding their way under existing funding structures promoting research and innovation. The following XR projects have been funded through Horizon 2020 (H2020).

Examples of EU-funded XR projects

Project name	Short description
ARETE	Use of AR in education to build a pan-European competitive ecosystem
ARTwin	AR cloud platform and digital twins for Industry and Construction 4.0
Iv4XR	Verification and validation for XR systems based on AI techniques
Invictus	Delivering innovative authoring tools for the creation of a new generation of high-fidelity avatars
PRESENT	Creates virtual characters guiding in AR, VR and traditional interfaces
PRIME-VR2	Serious gaming virtual space for rehabilitation purposes
TACTILITY	Incorporates tactile information into new interaction systems for immersive VR
VRTogether	New media formats to increase the feeling of realism and (co-)presence by enriching existing production pipelines and practices

Another significant development at European level since Ecorys' VR 2016 report is the adoption of the European Digital Strategy[8] which, even though it does not entail a dedicated approach for XR technologies, is paving the way for an increased development, deployment and update of impactful XR. The strategy is enhancing key technological capabilities (i.e. progressing towards ubiquitous ultra-high bandwidth through 5G deployment, increasing resilience towards cyber threats through a comprehensive cybersecurity strategy) in Europe, which are enabling stronger and safer XR. In addition, the strategy is promoting competitiveness of the European digital industry, including the XR industry through various initiatives and funding opportunities supporting complex digital research projects (i.e. through Horizon Europe), upstream and downstream SMEs (i.e. through the Digital Innovation Hubs network) and start-ups (i.e. through Startup Europe). The European Digital Strategy is also addressing at European level critical legal issues (from copyright to standardisation and data protection) to support the European Digital Single Market and ensure a sustainable, ethical and inclusive digitalisation of industry.

The benefits of public-private partnerships

We often find public-private partnerships and other types of publicly funded initiatives that have led or supported the creation and growth of the most active XR hubs in Europe. This is the case for London – the largest XR hub in Europe – which has benefited immensely from structures such as the Digital Catapult promoting the development of innovative XR applications. Another example is Laval, which, as a hub, was put on the European and global XR map thanks to the creation of Laval Virtual (event and centre for innovation). Laval would not have been realised without public-private collaboration.

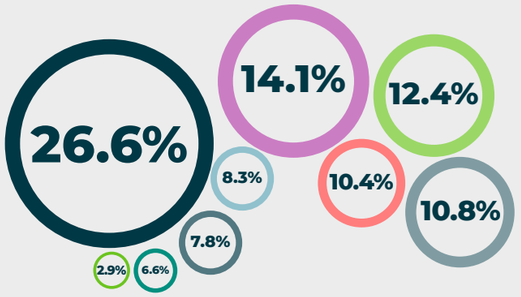
Since Ecorys' VR 2016 report, the digital innovation hubs are playing a pivotal role in a similar way in supporting local communities with digitalisation. These hubs are typically offering incubator and accelerator services, as well as acting as competence centres and providing access to resources and technical equipment. Even though XR as a technology is not identified by the EU as a priority focus area for digital innovation hubs, many digital innovation hubs are providing their services to XR start-ups and SMEs. For instance, Helsinki XR centre is also part of the successful development of Helsinki's XR scene.

The infographics on the next page illustrate different characteristics of EU companies based on the findings of the Ecorys XR industry survey, see methodological note in Annex II.

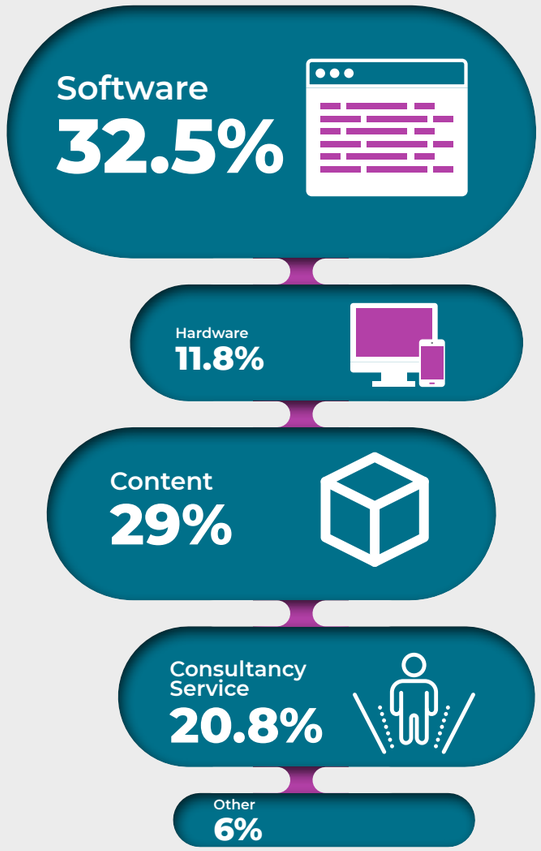
8 European Commission (2020), *Shaping Europe's digital future: The European Digital Strategy,* available here.

Structure of European XR companies

Most common funding sources by number of companies that used each

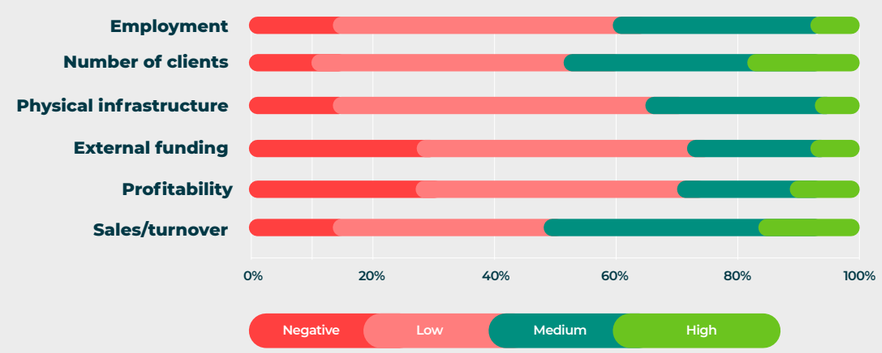


Type of product or service by number of companies



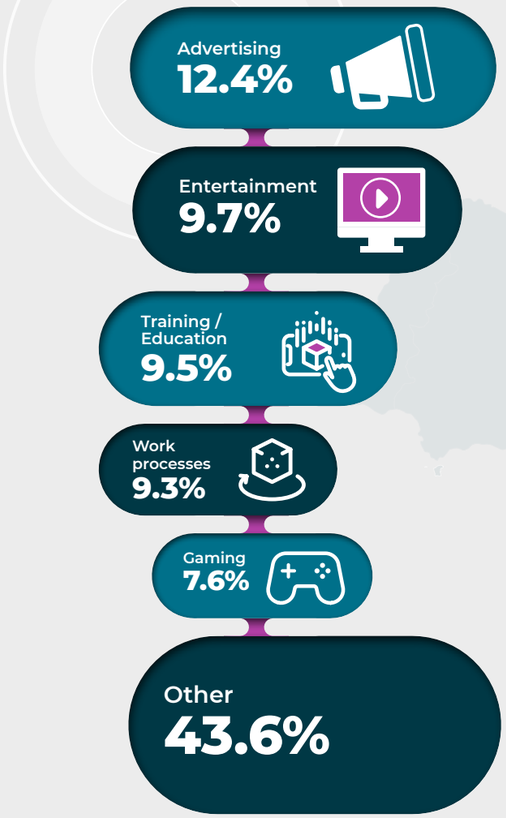
Size of companies by number of employees

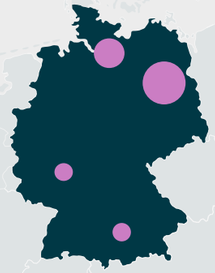
Estimates on growth during the period 2017-2019 by number of companies

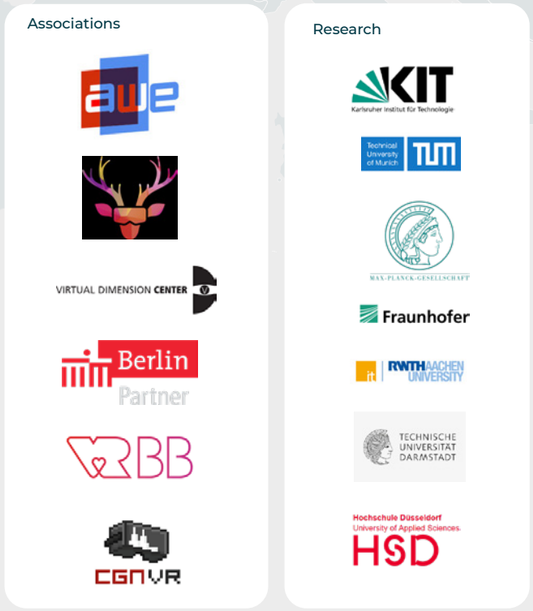


Source: Ecorys (2020), XR Industry Survey, see methodological note in Annex II.

3.1 Germany







Since the analysis in Ecorys' VR 2016 report, Germany has become the most prominent European country in XR development. This is largely due to its increasing industry demand and willingness for experimentation with new technologies. Germany is evolving as a major player in XR in Europe, as well as globally. Berlin stands out as the biggest hub, but cities such as Hamburg, Munich, Cologne, Stuttgart and Darmstadt now also feature prominent XR ecosystems. The German capital attracts creative thinkers, and the number of start-ups in the city has rapidly increased over recent years. Entertainment and media are key drivers for the Berlin XR scene, favouring a dynamic and volatile ecosystem. The situation is different in Southern Germany, where in cities such as Munich, Stuttgart and Darmstadt, XR applications are mainly utilised in large manufacturing processes, particularly in the automotive sector.

Germany's industrial centrality, together with rich state support for entrepreneurs, is allowing the creation of synergies between XR and most industrial sectors. Amongst them, the most notable are construction and healthcare, due to the presence of big companies that can take on the costs of innovation and implementation.

Health Reality[9]

Health Reality is a project born in Germany and financed through the European Regional Development Fund, which aims to explore and map potential applications for VR and AR in the healthcare sector. With some elements of a market study, the project will investigate which applications are already mature enough for commercialisation, and which ones show greater potential in the future.

Through its Health Reality platform, the project also ties the healthcare sector to creative applications. The gamification of healthcare procedures to improve clinical results is gaining momentum and relevance amongst experts[10], and XR shows great potential in this context. The Health Reality platform increases awareness and networking opportunities for these applications.

The presence of several regional hubs is fostered by the presence of various networking and knowledge-sharing associations spread over the territory. Several of them represent regional or city realities, showing a high presence of activities in local contexts. On top of these associations, Germany is continuing to build on its longstanding research traditions and education system. German research centres and universities are actively working on immersive technologies, and university courses devoted to XR are being developed throughout the country. In addition, strong links can be observed between research and industry through joint research and development initiatives.

9 Lokal Kompass (2020), *Kreative Anwendungen im Gesundheitswesen einsetzenhealthcare*, available here.
10 See for instance: Phillips E. G. Jr., Nabhan C. and Feinberg B. A. (2019), *The gamification of healthcare: Emergence of the digital practitioner?*, available here.

3.2 United Kingdom

The UK remains one of the biggest European immersive technology markets, and one of the leading countries in the world[11]. London has a thriving range of XR start-ups and projects and remains the biggest XR hub not only in the UK but in the whole of Europe. Other regional hubs have gained momentum in recent years, however – especially those in the greater Manchester area and the urban areas surrounding Bristol and Brighton.

XR activities include both industrial applications and production of creative content, building on the strong ties London holds with businesses in continental Europe as well as digital giants in the United States' Silicon Valley. The automotive and defence sector, as well as entertainment, cinema and news coverage, are good examples in the UK. UK VR/AR companies therefore rely on higher-than-average access to Venture capital (VC) funding in comparison to other European ones. This has created thriving hubs where numerous start-ups can take their first steps.

Another positive element for the establishment of a flourishing ecosystem is the cooperation between research/academia and businesses. Many of the main UK universities are developing programmes focusing on XR skills, creating the skilled workforce necessary for the technology to flourish. Moreover, ties with network associations help with the provision of financial, business and technical support.

Innovate UK – the UK governmental innovation agency – works in close collaboration with these network and research associations, promoting the technology and the start-ups in the sector through various channels (see box below). Innovate UK's activities reflect the interest that British public authorities have in immersive technologies. The high availability of private capital is complemented by the presence of public funding, further incentivising small XR companies to start their businesses.

Innovate UK[12] support policies and the Digital Catapult[13]

Innovate UK is the UK governmental agency for supporting and providing funding for businesses in order to contribute towards their (digital) innovation efforts. Through a variety of different channels, the UK government is providing funding, know-how and mentorship and tax incentives.

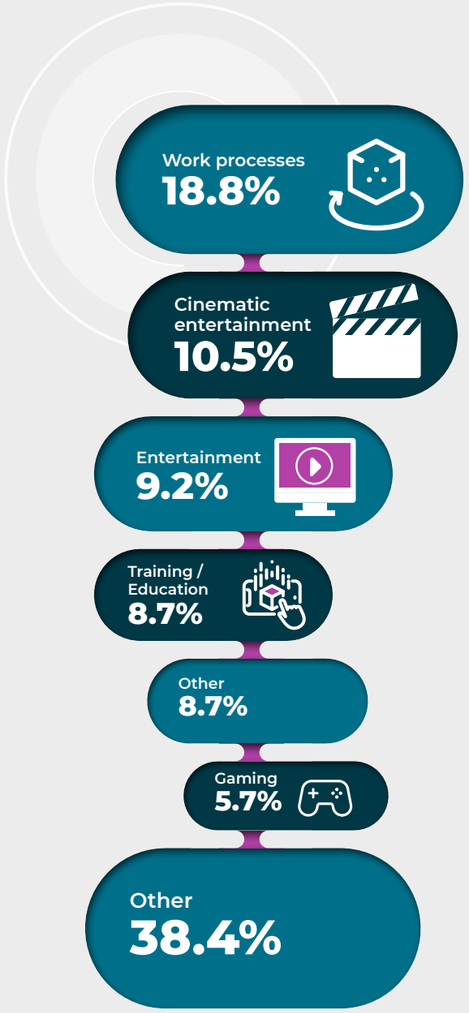
British authorities have been particularly supportive of XR technological developments in recent years, and this has not changed, despite the negative impacts of COVID-19. In May 2020, Innovate UK announced that an additional £20 million (around €22 million) in funding would be dedicated to digital innovation under the Fast Start[14] programme.

While the funding is not solely dedicated to XR activities, several projects proposing immersive solutions will benefit from the increased budget.

The UK's advanced technology innovation centre (Digital Catapult) has identified XR as one of its key focuses along with AI and ML and future networks (i.e. 5G, IoT). The organisation has been instrumental in the development of London and the UK as a key XR hub, through supporting start-ups in particular within the creative entertainment area through initiatives such as immersive labs and their dimension volumetric capture studio.

11 Immerse UK (2019), *The immersive economy in the UK Report*, available here.
12 Innovate UK
13 Digital Catapult
14 Innovate UK (2020), *Extraordinary times demand new energy in supporting businesses*, available here.

3.3 France



France is one of the most active countries in Europe in terms of the VR/AR industry. The two main hubs are Paris and Laval. Paris is the core of French XR activities, hosting numerous companies and start-ups that produce creative content. The latter, despite being a rather small town in northern France, is nowadays renowned for hosting Laval Virtual, one of the most awaited and acclaimed XR events in Europe. Other important hubs in France are Lille, Strasbourg and Bordeaux.

Industrial applications are particularly important in France following recent trends. Since Ecorys' VR 2016 report a more intensive increase is observed in enterprise rather than commercial uses of XR. The French automotive and defence sectors are particularly strong, and utilise XR for applications ranging from product design to prototyping and logistics, encompassing almost the entirety of the business and production processes. Training and remote collaboration are also highly popular, and demand for them has increased due to the COVID-19 pandemic.

Centred in Paris, creative- and content-focused XR production is thriving in France. Several cultural initiatives have been established, often supported by public authorities. These include art, media and cinematic and 3D video production initiatives. The promotion of French culture using new technologies is gaining momentum and is proving effective. These XR activities are facilitated by the presence of one of the biggest gaming networks in Europe in the country, making it closely connected to immersive technologies in terms of skillsets.

culture vr[15]

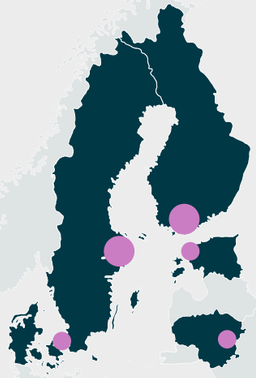
culture vr is an initiative of the Institut Français, a public institution that promotes French culture worldwide. The Institut Français provides support for all cultural activities, from artistic creations and linguistic cooperation to intellectual exchanges aimed at spreading French culture.

culture vr is a directory of French works and VR creations, comprising a professional network. Its scope is to make information and knowledge on French VR artistic content more accessible, and to help content creators obtain the contacts necessary to conduct their business. Launched in 2017, it now references 150 works alongside the professionals in the field involved.

These activities are supported by strong French research traditions and education systems for new technologies. Several universities have programmes and courses dedicated to (or including) XR technologies, allowing for the formation of new, skilled professional figures. Public initiatives supporting content creation and start-ups, together with category associations that promote networking and knowledge exchange, further stimulate the ecosystem.

15 culture vr

3.4 Nordic and Baltic countries



The Nordic countries have an established reputation when it comes to innovative technologies, which applies to both business realities and the average level of technological competence of the population, due in particular to the high quality of life enjoyed in these countries. In terms of XR, Stockholm and Helsinki are the two hubs that immediately stand out. Other regional hubs, like the Copenhagen area, are increasing in importance despite the rather small share of the market they represent. Baltic countries have a different background and a lower level of involvement in XR, but an emerging scene can be observed in Vilnius and Tallinn.

Most XR applications are related to entertainment and gaming, as well as cinematic industries, which focus on the production of creative content. This is fostered by the presence of a strong gaming community, which over the years has naturally started to develop XR products. Industrial applications are also present, however, and different companies work on the hardware side (especially in terms of high-end creation, producing precision electronic products and state-of-the-art headsets). Products in the field of optics, consumer electronics and engineering are amongst the strengths of the Nordic and Baltic ecosystems.

Varjo[16]

Varjo is a Finnish company based in Helsinki which produces VR and MR headsets, mainly for enterprise use. It is considered amongst the most advanced XR companies in the world and is praised for the extremely high quality of its headsets. Varjo has won several awards in recent years, including 'Product of the Year' at the Helsinki Design Awards, the 2019 'Lumiere' award and 'Best Exhibitor' at the Volkswagen KTVT.

Thanks to the quality of its headsets, Varjo is one of the only companies in the Nordic and Baltic countries that has received a large amount of private funding, including its most recent collaboration with Epic Games.

Its flagship headset, the Varjo XR-1, promises to be the first photorealistic MR headset, seamlessly blending the augmented environment with the real one. The digital content is indistinguishable from the real world thanks to advanced technologies such as high-quality visual fidelity, ultra-low frequency and integrated eye tracking.

The ecosystems surrounding the main hubs feature a good overall integration between academia, universities, networking organisations and incubators, facilitating companies interested in starting an XR business. The quality of research is extremely high and often applied to business processes. As in most of Europe, however, the number of specialised degrees is not particularly high, and this can create difficulties for companies attempting to access talent in the sector.

Associations, which are often present in the territory at a local level, help to create a sense of community and guide start-ups through technical assistance initiatives and networking opportunities.

Since Ecorys' VR 2016 report, new entities such as digital innovation hubs have been pivotal in supporting XR start-ups. A bright example is Helsinki where several supporting organisations and initiatives have been recently established. Technological developments are further facilitated by the higher-than-average quality of the digital infrastructure, especially in Finland and Sweden.

Moreover, public support and investments are in place to further help start-ups. Access to public funding is closely linked to research and is part of governments' efforts to keep their countries amongst the most tech-savvy and innovative in the world.

16 Varjo

3.5 Benelux and Ireland

The XR ecosystem in Benelux and Ireland is well established. The Netherlands is the biggest activity centre, with Amsterdam being one of the most important hubs in Europe. The Belgian Brussels' hub is also gaining importance, thanks to its strategic position in the political heart of Europe. Ireland represents a peculiar reality, while its capital, Dublin, and the surrounding area are developing a flourishing XR ecosystem the country is particularly important due to the presence of many US digital giants attracted by the favourable tax conditions.

The wealthy economies of the area offer a favourable environment for start-ups, with both private venture funds and public measures that support innovation available. Ireland and the Netherlands have a great tradition in terms of innovative digital technologies, and the XR industry is building on that. XR industrial applications are becoming more popular, following the general trend towards Industry 4.0. Biotechnologies, agricultural technologies and pharmaceuticals are amongst the strongest industrial sectors in the region. Most of the XR ecosystem, however, focuses on services and entertainment, with big players in the retail and banking sector beginning to use XR for marketing, as well as increased efficiency and safety in the workplace.

Virtual Park[17] and Vertigo Games

Located in the small Belgian town of Mouscron, at the border with France, Virtual Park is the biggest Virtual and Augmented Reality park in Europe, covering 4,000m². The leisure and gaming activities include the use of VR rooms, full-body VR suits and AR/VR headsets. Moreover, it offers a VR theatre and the opportunity to engage in team-building exercises.

Another VR success story is that of the Rotterdam-based Vertigo Games, developer of the 2016 hit Arizona Sunshine. An established publisher with a loyal fan base, Vertigo Games was bought in September 2020 by the German-Austrian giant Koch Media, one of the biggest producers and marketers of digital products in Europe. The acquisition cost around €50 million in stock and cash, and demonstrated the increasing interest of big entertainment companies in XR.

Belgium, in particular, hosts several events and XR associations, due to the presence of EU institutions that offer networking opportunities and visibility. Moreover, the strong Dutch gaming ecosystem offers a variety of sectoral organisations. In terms of universities and research, the Benelux area in particular is regarded as one of the most innovative in the world. XR talent can develop thanks to several dedicated university programmes, but often these individuals move to other countries due to the relatively small size of the companies in the sector.

In terms of public investments and incentives, both Benelux and Ireland can offer opportunities for companies. In terms of tax incentives and innovation funds, Ireland's government agency, Enterprise Ireland, provides technical support in the form of feasibility studies and a dedicated foreign direct investment strategy to attract foreign capital.

17 Virtual Park

3.6 South-West Europe

The Iberian Peninsula XR activities are conducted in Spain, with most of them centred around Madrid and Barcelona. The Spanish capital acts as a catalyst for industrial applications, while Barcelona attracts smaller creative start-ups focused on entertainment and visual content. In Portugal, the main hubs (besides the capital, Lisbon) are Porto and Braga. In Italy, instead, most XR activities revolve around the industrialised North, with Milan and Turin serving as the main hubs. Industrial applications in this area are often related to the automotive sector, other manufacturing solutions (mainly aeronautic/space and maritime/nautical), luxury fashion, design and furniture, and, of course, cultural heritage.

The XR ecosystems of each country have strong ties with the tourism sector, one of the most important sectors at the national level. This is especially true for smaller XR realities, which lack the critical mass and the higher level of investments necessary to work on industrial solutions. The lack of availability of both private and public funding still hinders the strengthening of the XR ecosystem outside of the main hubs.

In fact, Iberian public authorities, in particular, have put in place a relatively limited number of initiatives and incentives to support industrial digital innovation. The situation is more positive in Italy, where the government has put in place plans for investment in the implementation of Industry 4.0, mainly through tax incentives. One of the main issues in all three countries remain the small dimension of companies, often run by families, which makes them reluctant to invest in new and expensive technologies.

The Iberian community, in particular, benefits from the work of several networking associations, as well as from stronger academic and research efforts. The creation of XR talent is not always supported by dedicated university programmes or by awareness-raising campaigns, which could raise interest and provide the proper skills to younger generations. Nonetheless, all three countries are witnessing a growing interest in immersive technologies from the research side. Many universities are developing cutting-edge technological programmes and facilities to support investigations for future development, as highlighted in the box below.

University of Deusto Immersive Lab[18]

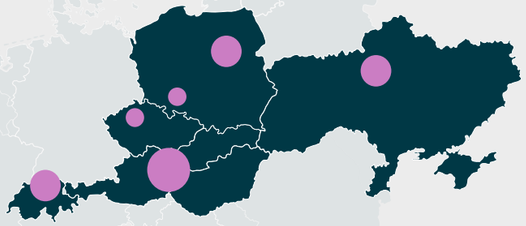
In collaboration with the Spanish company Virtualware, the Basque University of Deusto has opened at the end of 2019 its own VR lab, the first one in the world of its kind. The Laboratory of Immersive Technologies Virtualware-Deusto – the official name of the lab), part of the Engineering Faculty, will allow students to access a dedicated space for research experiments. Students will have the chance to develop virtual and AR projects as part of university courses and in relation to a number of subjects.

Virtualware[19], the producer of the XR technologies used in the lab, create immersive rooms of variable size, easy managed and set-up by their Viroo system. Moreover, multiple users can be present in the immersive room at once thanks to the Nmerso solution[20].

Iberian companies enjoy a special relationship with Latin American countries, providing an additional channel for commercialisation of their XR products. In particular, Portugal has strong cultural and historical ties to Brazil, the biggest market in the region and one of the fastest growing in the world.

18 Virtualware (2019), *World's first virtual immersive room unveiled*, available here.
19 Virtualware.
20 More information here.

3.7 Central and Eastern Europe



XR activities revolve around the well-established centres of Vienna and Zurich, which can rely on a dynamic start-up environment of high-quality support structures and accessible VC funding. However, new centres towards the east, like Prague, Warsaw and Kiev, are growing, especially when it comes to the gaming industry. Since our previous 2016 VR report, the number of XR start-ups born in the region has steadily grown. This positive trend is characterised by the international thinking of many of these start-ups, aware of the relatively small size of their national markets, and by their product-driven approach and good level of technical expertise.

Switzerland and Austria have a specific tradition with regards to medical and bio-science applications for XR due to their research centres in the field. Many world-class universities are investigating the subject, and immersive technologies can play a major role in innovations to the way healthcare practices are conducted. Switzerland has several networking organisations that link start-ups with the relevant support. The other national realities are still less organised, but their ecosystem sets the basis for further development.

This is particularly true for the gaming industry, with Poland, Czechia and Ukraine leading the way. Aside from traditional gaming companies – with CD Projeckt Red (a Polish game developer) rivalling the French giant Ubisoft, in terms of total revenue in Europe – a specialised niche of VR games is rapidly growing.

Superhot VR and Beat Saber

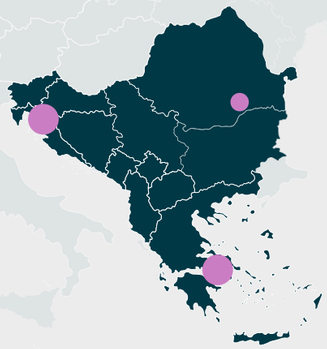
Created by the Polish 'Superhot Team', based in Lodz, Superhot VR is one of the few video games developed for VR to receive critical acclaim and widespread public success. While originally launched in 2016, the game was enhanced and improved in terms of VR interaction and released in mid-2019 for several headsets, including PlayStation VR, HTC Vive and Oculus Rift.

Building on the first-person shooter video game genre, Superhot features a characteristic mechanic where time passes only as the player moves, allowing them to better assess the situation surrounding them and act accordingly in response.

The success of Superhot confirms the potential that VR holds in the video game industry, as well as the growing tradition in the sector in both Poland and Central-Eastern Europe. Another VR killer application, Beat Saber, was released in 2019 and became one of the most popular VR games ever, selling over 1 million copies in less than nine months. The developer, the Czech company Beat Games, was soon after bought by Facebook's Oculus division. This purchase proved huge for the company and for the Central-Eastern European game community.

Industrial applications show potential, especially in relation to the automotive (Skoda) and utilities sectors. Most XR activities are, however, related to digital content creation and services, such as consultancies.

3.8 South-East Europe



South-East Europe is not a leading area for XR, but a number of regional hubs have been growing over the years, setting the stage for further development. Capital cities are the economic hearts of the countries in this region, and their surrounding areas tend to be the main XR hubs as well. Athens is the main centre of activities, but emerging XR scenes are also developing in Zagreb and Bucharest.

The industrial reality of the region makes it more difficult for developers to create related industrial solutions. Many companies are hesitant to undergo the investments necessary to implement XR solutions into their workflow, as attracting private capital can prove complicated. However, in recent years, new companies and solutions that are now able to attract VC for digitalisation have started to emerge, thanks to the level of maturity reached by XR technologies. The situation is also improving in terms of public funding, as some governments offer some degree of tax incentives for implementing digital technologies.

The region tends to focus on XR-related services such as consultancy, marketing or advertising, and on the tourist sector, crucial for these Mediterranean countries. Most of the industrial applications are related to branding and marketing purposes.

VR and AR in tourism

More initiatives are starting to offer VR tours to promote the cultural and natural beauty of Mediterranean locations. These solutions allow users to visit cities and coastal areas, either through 360° video technologies or VR headsets, without leaving their homes. This is particularly beneficial for tourist locations during the COVID-19 crisis and its aftermath. Moreover, onsite tourism can be enhanced through AR applications, offering real-time contextual information on the point of interest that is framed.

One of these projects has been developed by the University of Athens, and allows a virtual tour of the Greek capital, with many tourist companies offering enhanced experiences of the city's Acropolis. Most of the countries in the region offer similar services, including 3D virtual tours of the Albanian capital Tirana, Dracula's castle in Romania and Diocletian's Palace in Split, Croatia.

Several initiatives are under development in Italy, thanks to the sheer number of cultural attractions (Pompeii, the Colosseum and thousands of museums and villas). The restrictions due to the pandemic have laid the groundwork for the creation of various projects.

While research is being carried out by important universities and national centres, there is still a lot to be done to ensure the uptake of XR technologies and the creation of a strong community of talent and skillsets. Dedicated university programmes can be found mostly around the biggest hubs in the region. Research centres and universities in the region have limited access to regional and national funding, such as the Western Balkans Fund, and face high competition from bigger and better-placed European centres when applying for European-level funding.

4 XR and the digital transformation of Europe

XR can act as a keystone of Europe's digital transformation. XR applications are shaping and revolutionising business processes, from manufacturing and product development to collaborative working and customer relationships.

The digital transformation of businesses is a global trend, transforming work processes and the way we conduct tasks. It concerns all types of organisation and the European Commission has made 'Europe fit for the digital age' one of its key political priorities for the 2019–2024 period. The aim of the EU is to become a global leader in terms of a digitalised economy and support the ongoing digital transformation of the European industry. The implementation of digital solutions is expected not only to increase the competitiveness of the industrial sector, but to help the EU provide solutions to social and environmental issues, for example to reach its objective of becoming carbon-neutral by 2050[21].

The EU's policy approach is based on its long-term strategy, Shaping Europe's digital future[22], which focuses on creating a competitive digital economy by supporting the industry with additional funding and further regulating new areas such as AI and privacy. Funding for digital projects or solutions is envisaged under a variety of initiatives under the Multiannual Financial Framework 2014–2021 (MFF), such as the European Structural and Investment Funds (ESIF, with €21.4 billion dedicated to the digital sector), the European Fund for Strategic Investments (EFSI, foreseeing €37.8 billion in digital investments) and the Connecting Europe Facility (CEF, devoting roughly €1 billion to ICT infrastructure). H2020, which supports the already flourishing European research area, not only offers around €5.5 billion to digital research, but is stepping up its technical support system by strengthening the digital innovation hubs (DIHs). The European digital strategy is implemented through additional policy actions targeting the European industrial fabric. Particularly relevant are the new European Industrial Strategy[23] and the SME Strategy[24]. The Industrial Strategy considers digitalisation as a top priority for the renewal of European industries, together with the green transition and the role of Europe as a global leader. It stresses the importance of a healthy industrial ecosystem able to connect authorities and the academic and research community together with companies – whether they are service providers, SMEs or larger companies. On the other hand, the SME Strategy focuses on smaller companies, the heart of the European industry, by providing funding, access to business and technical support through the DIHs and support to breakthrough digital innovation thanks to the new European Innovation Council (EIC).

21 European Commission (2019), *A Europe fit for the digital age*, available here.
22 European Commission (2020), *Shaping Europe's digital future*, available here.
23 European Commission (2020), *A new industrial strategy for Europe*, available here.
24 European Commission (2020), *An SME strategy for a sustainable and digital Europe*, available here.

Benefits of digitalisation

Digitalisation is a process with various benefits, both for the industry and for European citizens. In macroeconomic terms, it has been estimated that by 2025 the overall global value brought by digital transformation will exceed €83 trillion[25], hinting at the importance of digital technologies in our society. These macroeconomic benefits stem mainly from two sources: the creation of new jobs and the requalification of others, and the increased efficiency and competitiveness of companies, proportional to their level of digitalisation.

With regards to the former, the potential impact of digital technologies on the labour market has been analysed in previous research. Estimates in such analyses emphasise the substantial positive impact of the Digital Single Market, which could create up to 2 million new jobs[26].

The benefits enjoyed by companies, on the other hand, regard different aspects of their day-to-day work. Digital technologies can transform the way traditional tasks are carried out, leading to cost and time savings. A developed industrial data framework would help the industry to optimise workflow, gathering insights from customers – thus allowing an enhanced customer experience – improving data collection and resource management. The combined effects of the transition would therefore lead to more efficient, digitally savvy and productive companies.

4.1 How XR contributes to digital transformation

XR technologies have the potential to increase Europe's digital capabilities by conducting traditional tasks in more innovative, faster and more cost-effective ways. Moreover, it can increase the safety of workers and help companies counter the negative impacts of the COVID-19 pandemic. Increased efficiency, with consequent cost and time savings, is the main driver behind the adoption of XR solutions, although other factors, such as increased security in the workplace, can play a role. Enterprises using XR solutions have seen a boost in recent years, demonstrating the growing interest of companies in the technology. XR for enterprises is set to outpace commercial uses of the technology, given its proven benefits for businesses and employees[27].

Immersive technologies have the potential to change the way many businesses operate, from manufacturing processes to training employees, product design and marketing. Studies have started to address the topic to demonstrate the added value of certain uses of XR in learning processes[28] and the savings in terms of cost and time. However, many European companies are still not tapping into these potential benefits either due to low awareness or because they do not have the support or the personnel necessary to implement them in their workflow.

The potential of XR to change and digitise production and business operations is categorised by area of application. The potential of each application differs depending on the industry and sector considered.

25 World Economic Forum (2018), *Digital transformation initiative*, available here.

26 European Parliament (2019), *The European Digital Single Market: Delivering economic benefits for citizens and businesses*, available here.

27 VR Intelligence (2019) 2019 *XR Industry Report*, available here.

28 El-Jarn and Southern (2020), *Can co-creation in extended reality technologies facilitate the design process?*, available here, or Kaplan, Cruit, Endsley, Beers, Sawyer and Hancock (2020), *The effects of Virtual Reality, Augmented Reality, and Mixed Reality as training enhancement methods: A meta-analysis*, available here.

Manufacturing processes

Assembly and **maintenance** fall under this category. These activities can be carried out more efficiently with the help of XR technologies. In the first instance, personnel can visualise real-time instructions overlaid on the product itself, minimising mistakes and the need for onsite support from experts. This is an important asset in manufacturing industries such as the automotive, aerospace, electronics, chemical and pharmaceutical sectors, where machinery can be assembled faster and more efficiently. The maintenance is rather similar in terms of facilitated human intervention, but with additional benefits such as synergies with other technologies. Sensors sharing data can in fact prolong the life of machinery, adjusting settings to their ideal values, and can highlight, thanks to AR, the piece or pieces that need to be replaced or attended to.

In particular, AR can offer the possibility of speeding up other parts of the manufacturing process. For instance, when selecting **raw materials** to be transformed into manufactured products, staff can access at-a-glance information. This also applies to general **set-up** and **production** processes.

Product development

VR technologies can support the creative process behind applications such as **product design** and prototyping. The possibility of visualising objects in a 3D environment makes the design phase more intuitive and allows for an easier interaction between the manufacturer and the client. The latter can provide more timely feedback and steer the creative process towards the desired result.

Prototyping through VR implies reduced costs and use of materials for companies. Building multiple physical prototypes takes time and leads to negative environmental consequences. Immersive technologies can tackle both issues, especially in sectors where prototypes are particularly material intensive and expensive to build.

Collaborative working

Throughout 2020 we observed a shift to digital solutions due to the COVID-19 crisis. The VR possibilities for remote working range from meetings and training to co-design, control and maintenance. Despite their numerous advantages, these solutions have not yet been fully exploited. Virtual meetings have gained widespread popularity, especially due to the COVID-19 crisis, and are starting to become the new normal in many workplaces. However, the most common services in the area do not make specific use of VR technologies, which could further increase their potential by improving the meeting experience. Virtual meetings conducted in a 3D environment allow for deeper interaction between attendees, who can share objects such as whiteboards and use them simultaneously. In the future, meetings could be conducted directly on the virtually recreated production line.

The second category – **remote guidance and supervision** – is one of the most mature and widely used by companies in the industry. Experts can provide real-time support to personnel onsite without the need to travel, saving money and time while reducing their carbon impact. They could also superimpose instructions if personnel are provided with AR headsets or devices, further improving their efficiency.

JoinPad[29]

The company offers an AR remote collaboration product, which can be run by any type of device, including smartphones. Experts can remotely support onsite technicians by adding digital and augmented elements to their device in real time. This improves collaboration, while reducing the need for costly and time-consuming on-field assistance.

JoinPad has estimated that thanks to this solution, on-field operation costs can be cut by up to 75%, while reducing downtime on production by up to 30%.

The company also developed a new solution related to the COVID-19 crisis. It created new smart glasses able to measure body temperature automatically and rapidly while maintaining distance and collecting aggregated data.

Customer relationship

Immersive technologies can change the way companies interact with their clients. They can attract them during the **marketing** phase or offer new services and an innovative customer experience.

Companies use XR to promote their products in many new ways. For instance, they can recreate touristic locations and place their product in them or create hologram-like experiences through MR technologies. Examples of this in practice include virtual tours of hotels, virtual booking interfaces and travel experiences. The sense of novelty surrounding the technology and the additional interaction can attract positive feedback from potential customers.

In terms of **customer experience**, XR allows customers to visualise products without leaving their homes. For instance, IKEA offers an AR service that imposes digitally reproduced furniture over the picture of the user's room. Or, in the real estate market, realtors can show potential customers what a house could look like once finished, thus finding buyers before the project is completed, organise virtual tours of the property and show a furnished room despite the room being empty.

Horizontal activities

When it comes to horizontal activities, we can find several relevant XR applications. These include **data visualisation and video production**, including movie production[30]. With the ever-growing amount of data available in the modern world, the possibility to visualise them in an intuitive way can be valuable to companies. VR offers a 3D environment to further increase potential interaction with these flows of data, allowing them to be presented in an orderly and coherent fashion.

XR also helps to speed up **administrative** and **logistics**-related tasks. The adjacent box presents some of DHL's findings with regards to the potential of AR in this area.

29 JoinPad
30 With the potential for XR to improve the overall production process.

DHL's application of AR in logistics

The German delivery giant DHL published a report[31] listing a series of advantages provided by AR in carrying out tasks in logistics. The report classifies cases through the following categories:

- **Warehouse operations**: AR facilitates the picking process, traditionally carried out with paper forms. AR solutions can scan codes, highlight the order to be picked and indicate the fastest route to reach the objective. The overall planning of the warehouse can also be enhanced thanks to AR.
- **Transportation optimisation**: AR solutions can help transportation in a variety of ways. They can speed up completeness checks before deliveries as well as loading, checking documents and translating parcels, providing real-time traffic support to drivers.
- **Last-mile delivery**: AR facilitates drop-off operations that help with freight loading, allowing staff to check the regularity of a parcel just by glancing at it. Moreover, drivers can easily identify and navigate buildings.
- **Enhanced added-value services**: in this category, the DHL report lists application areas such as assembly, repair and customer services.

One of the best-known XR applications involves conducting **training** sessions in a 3D environment. Applying VR and AR to training increases the interest of learners, thanks to its visualisation and natural interaction capabilities. The use of VR and AR for training enables one to understand phenomena and procedures in industrial processes more quickly and easily. Studies show that XR-based training reduces the duration of learning, improving the quality and memorisation of complex processes. Time and cost savings are not the only advantages. Safety considerations have been made as personnel are able to test potentially dangerous situations in a safe environment and easily repeat the scenario. Moreover, studies and anecdotal evidence show that people tend to learn better and faster during practical and immersive learning experiences rather than theoretical[32].

Lastly, XR can be useful when applied to **health and safety**. For instance, AR technologies can visualise radiological or biological hazards that are invisible to the human eye, or delineate safe areas around functioning robots. When working together with 'cobots' (a term deriving from the word 'collaboration' and 'robots'), staff need to be able to move around safely. AR can clearly show the path of the robot, allowing staff to avoid crossing it and therefore avoid danger.

31 Augmented Reality in logistics: Changing the way we see logistics – A DHL perspective, available here.
32 As suggested by several of our interviewees.

4.2 Drivers

There are several reasons why European industries could benefit from implementing XR solutions in their day-to-day work. While not all of these conditions are necessarily met by each application in every sector, there are common drivers.

The first and most important driver for implementation is **economic and time savings** deriving from using XR technologies rather than traditional processes. The possibility to create interactive virtual environments and objects entails less need for physical resources, for example in the case of design and prototyping. Moreover, AR-enhanced remote assistance, together with machinery able to identify parts that need fixing, would allow for quicker and more accurate maintenance and assembly, reducing the need for experts to travel.

However, implementation of a new and often unknown technology comes at a cost, especially for SMEs and start-ups. Therefore, the presence of **digital incentives**, as well as targeted funds, has helped companies to make these steps. While at EU level there are no funding or other support programmes specifically targeting XR technologies, funds are allocated for helping the digitalisation of industries. Strategic public funding can fill the gap preventing private entities from investing more – the so-called market failures – and unlock the true potential of the technology.

A third driver would be the **educational potential** of XR such as in training. People learn faster and better when given the opportunity to engage the entire body in a specific task. Through XR, they also have the chance to try a range of scenarios over and over, which entails both a trial-and-error learning process and improved immersion. Moreover, the gamification of learning, including the feeling of reward and the competition with other users, seems to have positive effects[33]. This also applies to medical rehabilitation processes and more generally to entertainment.

Furthermore, companies could be more inclined to adopt XR technologies if their **interaction with clients** is enhanced. This is true in relation to the general customer experience. Customers can have innovative interactions with products and more easily provide their feedback during the product design phases. This allows companies to adjust the manufacturing to their clients' needs. An innovative and effective way to improve this interaction is the 'try before you buy' approach where consumers are given the option to try a product before buying it online. This includes using AR to put an object in their room, using AR and facial recognition to try on make-up and visiting an apartment in 360°/VR (video or images) before deciding whether to rent or even buy it.

It is to be noted that XR technologies can reach (and monetise) a larger audience without being limited by the capacity of a room or building. Cultural institutions can sell more tickets to a performance, musical event or theatrical play if they record the event in 360° video and make it available in real time (live) or on demand (at a later time). The content can be made available for free or made available behind a paywall. This can also be used by other sectors, such as providing access to sports events. The audience can access the event from their homes, avoiding travel, long queues and crowded venues.

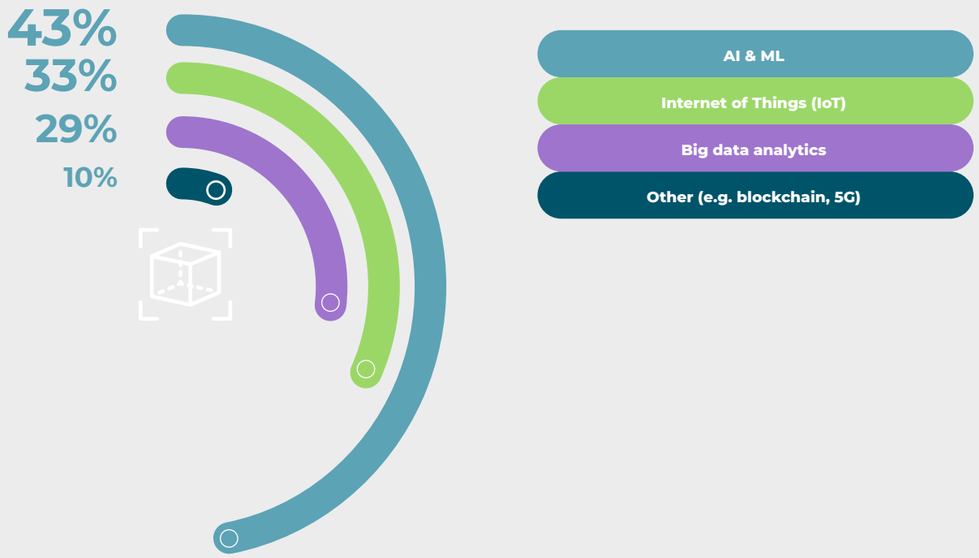
Lastly, XR can help public entities have closer interactions with citizens. AR enhances significant **citizen engagement** campaigns of public governments or institutions as it can involve the citizen at an early stage of public road works, for example. Also, sectors such as news reporting could benefit from XR technologies which could enhance the engagement rate and overall impact of the news reported. All major global news outlets such as *The Times*, Euronews, the *New York Times*, Arte France and *The Guardian*, are heavily investing in immersive journalism/documentaries.

33 Source: Stakeholder interviews.

4.3 XR and other key technologies

XR is a new technology which can greatly benefit from synergies with other emerging technologies and vice versa. Several companies surveyed indicated that their XR solution is fostering these synergies.

We asked European XR companies, whose XR solution is related to industrial transformation, which other digital technologies their product or service is enabling. Here are their answers:



Source: Ecorys (2020), XR Industry Survey, see methodological note in Annex II.

The interaction with AI is perceived to have the most potential[34]. AI-powered XR can learn from users' preferences, adjusting the experience and allowing for contextual selections according to the circumstances. The further development of AI will not only benefit clients but also XR developers. Spatial design requires additional tools and the potential to use a whole series of new inputs such as voice, sight, touch and gestures. In this sense, AI can enable designers to develop XR environments and experiences in a faster and better way[35]. Moreover, AI can automatically improve the behaviour of objects in the digital environment, enhancing the sense of immersion and facilitating coding.

The XR **IoT synergy** is considered to be extremely fruitful as well. As in the case of AI, development of the core technology would make it possible to collect data from real objects and to use it in the digital environment. Ensuring greater connectivity with real objects could improve the overall XR experience. In terms of maintenance, for instance, IoT-connected machinery could share information about internal damage to an AR device, showing personnel exactly where to intervene.

It is a similar situation when it comes to the use of **big data**. Perfecting the way fluxes of data are handled is necessary for AI solutions to be implemented. This way, big data could improve how XR solutions are designed and coded. On the other hand, XR could help with handling these streams of data, visualising them in a more intuitive way thanks to a 3D VR environment.

The 'other' category includes **blockchain, 3D capture technologies** and **5G telecoms**. 5G has been widely mentioned throughout our interviews, despite the rather low score obtained in our Ecorys XR industry survey. 5G would allow for faster transfer of data and benefit all XR applications that require a data streaming function. Thanks to 5G, real-time interaction and edge-cloud processing is now possible: this implies many complex processes can be shifted from user devices to the cloud, allowing even low-capacity devices to run certain rendering or processing tasks. Other important synergies relate to the **digital twin** concept. These are digital models of a physical system (the word has been defined for manufacturing/production systems) that, thanks to sensors and IoT tools, collect information and use it to feed data simulations, AI, ML and analytic software in order to build a faithful copy of the real system. In this complex system, the analysis of data flows from the physical component, enabling the automatic modification of the digital component to mirror the evolution or change of the physical one. On the other hand, the elaboration of data allows both the simulation (what/if) of an optimal reaction to external events as well as transmits commands to the physical component to implement the results of the simulation itself.

While the EU has not yet launched any flagship initiatives specifically targeting XR, several steps are being taken to promote other emerging technologies such as big data, AI and 5G, which are specifically mentioned in Commissioner Breton's key responsibilities[36]. These are also associated with dedicated initiatives and funds that are expected to boost their adoption and deployment in the coming years. For instance, the European approach to AI and robotics[37] builds a foundation to support grasping the full potential of AI in a way that is ethical, legal and respects European citizens' rights. The experience of the EU in setting up such a framework is crucial for creating tools and initiatives that could also cover or be easily adjusted to cover XR as well.

34 A result emerging from our workshop as well.
35 *CMO (2019), How AI-powered Augmented Reality transforms digital experiences*, available here.
36 European Commission (2020), *Commissioner (2019–2024): Thierry Breton: Internal Market*, available here.
37 European Commission (2020), *European approach to Artificial Intelligence*, available here.

4.4 Most promising applications

The applications described above show different potential according to the specific sector and industry, and to the technology considered. In fact, VR and AR have peculiar strengths and weaknesses which make them suitable for certain applications but not for others. The tables below indicate the potential uptake and disruption levels of the various applications distinguishing between VR and AR. The three sectors identified – manufacturing, healthcare and construction – have been selected as the early adopters of XR technologies in European industries. These categories are defined according to the NACE definition used by Eurostat[38].

Level of potential uptake and disruption of VR applications per industry

Level of uptake and disruption
Low
Medium
High
Technology not relevant

	Applications	Manufacturing (by NACE technology level)			
		Low/Medium-low e.g. food products, textiles, plastic products, wood products	Medium-high/High e.g. chemicals, electrical equipment, motor vehicles, pharmaceutical products, air and spacecraft, computer and electronics	Healthcare	Construction and architecture
Manufacturing processes	Assembly	✓	✓	✓	✓
	Maintenance	✓	✓	✓	✓
	Raw material preparation	✓	✓	✓	✓
	Set-up and production	✓	✓	✓	✓
Product development	Product design	✓	✓	✓	✓
	Prototyping and sampling	✓	✓	✓	✓
Collaborative working	Conduct meetings	✓	✓	✓	✓
	Supervision of activities/ remote guidance	✓	✓	✓	✓
Customer relationship	Marketing and advertisement	✓	✓	✓	✓
	Sales and customer experience	✓	✓	✓	✓
Horizontal activities	Data visualisation and video production	✓	✓	✓	✓
	Administrative tasks	✓	✓	✓	✓
	Training	✓	✓	✓	✓
	Logistics	✓	✓	✓	✓
	Health & safety	✓	✓	✓	✓

VR shows the biggest potential in the product development phase which encompasses design and prototyping. The possibility of interacting with a 3D model, without wasting material and easily changing various aspects of the product, can lead to substantial cost and time savings.

VR meetings could also become a new reality if headsets become more widespread. While virtual meetings do not require VR technology to be effective, they would certainly be enhanced. Over time, VR meetings could be conducted while showing a digital and interactive version of the work site, improving the quality, effectiveness and level of involvement. This is especially true in the manufacturing sector and in hospitals. It is also true with regards to remote guidance: while generally conducted with AR devices, VR can also play a role, especially in healthcare. Rehabilitation and tele-rehabilitation are already used worldwide and show great potential.

A third area showing potential is marketing. VR allows for new and innovative ways to attract customers, leveraging the novelty of the technology and the variety of interactions it allows.

Finally, the application indicated as perhaps the most noteworthy in terms of VR is training. Already amongst the most mature, VR training can be conducted in most sectors. It entails savings for companies and studies are starting to indicate that it is more effective than traditional learning methods. For example, staff can try safety drills in VR, experiencing otherwise excessively dangerous scenarios, with a more concrete feeling than with theoretical training and with the option to repeat the scenario whenever necessary.

38 Eurostat (2018), *Glossary: High-tech classification of manufacturing industries*, available here.

Level of potential uptake and disruption of AR applications per industry

Level of uptake and disruption
- Low
- Medium
- High
- Technology not relevant

	Applications	Manufacturing (by NACE technology level)			
		Low/Medium-low e.g. food products, textiles, plastic products, wood products	Medium-high/High e.g. chemicals, electrical equipment, motor vehicles, pharmaceutical products, air and spacecraft, computer and electronics	Healthcare	Construction and architecture
Manufacturing processes	Assembly	✓	✓	✓	✓
	Maintenance	✓	✓	✓	✓
	Raw material preparation	✓	✓	✓	✓
	Set-up and production	✓	✓	✓	✓
Product development	Product design	✓	✓	✓	✓
	Prototyping and sampling	✓	✓	✓	✓
Collaborative working	Conduct meetings	✓	✓	✓	✓
	Supervision of activities/ remote guidance	✓	✓	✓	✓
Customer relationship	Marketing and advertisement	✓	✓	✓	✓
	Sales and customer experience	✓	✓	✓	✓
Horizontal activities	Data visualisation and video production	✓	✓	✓	✓
	Administrative tasks	✓	✓	✓	✓
	Training	✓	✓	✓	✓
	Logistics	✓	✓	✓	✓
	Health & safety	✓	✓	✓	✓

Augmented reality is more promising in work processes that are conducted directly onsite and entailing closer interaction between the digital and physical world. This is the case for assembly and maintenance operations: overlaid digital information can optimise and speed up these processes. The more complex the machinery to be repaired or assembled, the higher the added value of an AR solution.

The same principle applies to remote guidance, which can be provided for assembly and maintenance activities as well. In this case, guidance is not provided by a software or training programme but rather by an expert remotely. The application of remote guidance AR solutions to the healthcare sector involves physicians specialised in specific surgical procedures who can provide remote assistance to colleagues on the other side of the world or support multiple colleagues in case of overcrowded hospitals.

AR shows great potential in terms of customer relationships. While VR seems more promising when it comes to attracting new clients, AR can offer them an enhanced customer experience. This is especially true in the construction sector, as estate agents can show the final look of an unfinished house and modify projects accordingly, or use 'try before you buy' models in retail.

Finally, AR may gain momentum and be integrated into the workflow of a number of horizontal activities, such as administrative and logistics tasks (see DHL box above) or in supporting safety procedures.

In line with the accompanying tables, surveyed companies indicated that their solutions contribute to the digital transformation mostly through virtual training, product design, prototyping, digital meetings, manufacturing and marketing and advertising solutions..

We asked European XR companies with XR solutions to industrial transformation, which industrial or business processes their product(s)/service(s) aim to digitise. Here is what they answered:

82% Training

48% Product design

48% Prototyping and sampling

46% Conducting meetings

46% Manufacturing (planning, set-up and production)

44% Marketing and advertisement

35% Data visualisations and video production

35% Sales and customer experience

28% Supervision of activities

16% Product packaging

13% Other

12% Administrative tasks

11% Raw material preparation

Source: Ecorys (2020), *XR Industry Survey*, see methodological note in Annex II.

4.5 Taking digital transformation to the next level

While XR is contributing to the digital transformation and revolutionising several processes, the benefits of a wider adoption could be multiplied, contributing to strong, sovereign and competitive European industries supported by the digital capabilities of XR.
The EU has taken a leading role in addressing challenges imposed by new technologies and fighting for an ethical and fair deployment of them with respect to human rights. This has been achieved through legislation, such as the General Data Protection Regulation[39], as well as other softer policy initiatives.

The European industry has gained vast experience in boosting digital transformation during 2020 where many business processes had to be conducted remotely due to the COVID-19 pandemic. Both industry and policy representatives could play a key role in addressing challenges hampering the uptake of XR solutions for digital transformation. Hereby, we present a list of challenges identified in relation to the progress of XR solutions that contribute to the industrial digital transformation.

Amongst the biggest challenges identified is the general difficulty of implementing XR technology in day-to-day work. This stems from a variety of reasons, such as data preparation, lack of experienced personnel in the field and the need to redesign business and industrial processes to include XR[40]. On many occasions, companies invest in an initial proof of concept (POC) to understand the solution, and after the initial use they do not translate the POC into a lease or purchase. This turns the POC into a service-based business, making investors think the solution (and therefore XR) is still not mature enough. This situation is not helped by the limited awareness shown by many CEOs in Europe, who are either unfamiliar with the technology and its benefits or unaware of the cost of buying an XR product. CEOs often have misconceptions about XR as they believe it is very technical and expensive, and that new and dedicated personnel are required to make it work. In reality, most solutions are now designed with non-technical employees in mind, and prices have dropped over the past few years.

While costs have been lowering, especially due to the reduced costs of hardware, implementation difficulties are exacerbated by the lack of investment in new technologies. Investments are particularly low in the private sector and from VC. Several stakeholders criticised the lack of entrepreneurial mentality in many European companies, preferring to only invest in products with with safe return on investment rates. Additionally, many promising European companies in the XR field face the possibility of being bought or receiving investments from outside of Europe, especially from the US.

Therefore, the private investment landscape should be better supported to address potential market failures.

This kind of difficulty can also be seen in the relationship between universities and research centres and the market. While the European research ecosystem is reputed to be one of the best in the world, especially in terms of digitalisation, the number of patents registered is proportionally not as high as it could be. This suggests that the private sector has difficulties translating research into products sold on the market.

Another set of challenges is connected to employees' relationships with XR technologies and headsets. Low digital savviness or reluctance to conduct tasks in a new way are often mentioned as obstacles for digitalisation through XR solutions. Additional common issues with headsets, such as motion sickness or lack of comfort, may worsen this problem.

39 European Union (2016), *Regulation on GDPR*, available here.
40 Source: Stakeholder interviews.

5 XR meets environmental sustainability

From awareness raising to conducting activities remotely and reducing the use of materials, applications are not only contributing to cost savings but also environmental sustainability.

XR applications with positive environmental sustainability effects will increase as a critical mass of users is reached.

5.1 Green Deal agenda and XR

'Climate neutrality', 'green recovery', 'decarbonisation of industry' and the 'promotion of sustainable lifestyle' have appeared prominently in the policy discussions across Europe in recent years and are here to stay. The **European Green Deal** is one of the main priorities of the 2019-2024 Commission. The communication announced the Commission's commitment to tackling climate and environmental-related challenges and indicated that 'new technologies, sustainable solutions and disruptive innovation are critical to achieve the objectives of the European Green Deal'[41]. To transform the European economy and generate new and sustainable competitive advantages for Europe, the EU is transitioning to a low-carbon, more resource-efficient circular economy and plans to allocate a budget for digital solutions supporting the transition. The European Green Deal also envisages the creation of the Innovation Fund, a funding programme with a specific focus on innovative low-carbon technologies. Moreover, the EU digital strategy, Shaping Europe's digital future, considers the environment as one of the crucial policy areas of intervention. The ICT sector can enable sustainability and reduce the carbon impact of many business and industrial applications. At the same time, the Commission is aware of the energy consumption and waste generated by new technologies and aims at addressing the issues through its own policy framework.

XR has the potential to contribute to the European Green Deal by promoting sustainable solutions directly by making certain processes and/or products more environmentally friendly, and indirectly by raising awareness and encouraging people to adopt more sustainable lifestyles. However, the primary motivation behind firms' adoption of immersive technologies is to increase efficiency and reduce costs. The impact on sustainability resulting from the use of XR is often a by-product and can be considered a positive externality. Nevertheless, increased efficiency resulting from the use of fewer resources means that the processes and/or products become more environmentally friendly. In addition, this positive side effect could become more important in firms' decisions to start using XR as customers' choices are increasingly being driven by sustainability considerations.

5.2 How XR contributes to environmental sustainability

XR as an enabler of eco-friendly behaviour and increased accountability

Immersive experiences can indirectly impact sustainability by **changing users' habits** towards more sustainable behaviour through raising awareness and sensitising them to the climate change consequences. XR can promote better understanding of nature and give people empathetic insight into environmental challenges. VR technology in

41 European Commission (2019), '*The European Green Deal*', available here.

particular tackles two of the biggest challenges of climate change communication: scale and proximity. Because emissions of greenhouse gases today will affect the climate far into the future, the temporal scale of climate change can be difficult for the public to comprehend. VR transports individuals into a future reality where long-term environmental changes can be experienced first-hand which, in turn, can encourage them to change their behaviour towards sustainability and demand policy change today. An example of such application is Be Earth #13[42], an immersive experience prepared by XR Impact – a non-profit organisation that leverages XR technologies to extend human sensory and cognitive experiences and inspire global action towards the UN Sustainable Development Goals.

Previous research on behaviour as a result of an immersive experience has found that participants adopted more eco-friendly habits. However, only a small number of studies have looked at longer-term effects. Additionally, the current low mass-market uptake of XR means that use of immersive technologies for awareness raising can be costly.

XR as a direct tool to decrease environmental footprint

XR technologies can directly contribute to environmental sustainability through several channels (see table below). By using AR and VR, organisations can **reduce waste and minimise the amount of resources** used in design and prototyping phases as well as in training for certain professions that require a lot of material (e.g. firefighters). CO2 emissions from the transport sector (responsible for almost one third of all emissions in the EU) could be reduced if VR and AR were used for remote collaboration more prevalently, thus **decreasing the need for travel**. A number of maintenance journeys could also be reduced (by allowing problems to be identified before arriving onsite) as well as journeys to retail outlets (by allowing consumers to visualise products at home).

XMReality[43]

AR allows engineers to visualise and identify problems before arriving onsite, which minimises the need for journeys to and from the site, reducing fuel consumption and negative impacts on the environment. AR makes it possible to send instructions over the internet so that people who are already onsite can solve technical problems without having to travel. For example, **XMReality Remote Guidance** enables users to talk, display, gesticulate, demonstrate, draw, write, point and show pictures and drawings. Some users of Remote Guidance managed to **reduce their amount of travel made by about 50%.**

Using VR/AR in construction and building design could lead to **energy savings**. For example, through VR, architects can assess how best to utilise natural light, reducing dependency on artificial light sources. Energy consumption could also be reduced by decreasing the number of physical shops as retailers switch to virtual shops to sell their products.

		Sustainability channel		
		Fewer resources/ less	Less travel (reduction in CO2)	Energy savings
Awareness raising	Immersive experiences such as gamified training and short VR movies have the potential to make users adopt more sustainable habits by raising awareness and sensitising them to climate change consequences.	✓	✓	✓
Remote maintenance	Engineers and other professionals can visualise and identify problems before arriving onsite, which minimises the need for journeys to and from site, thus reducing fuel consumption. In addition, the virtual presence of experienced professionals during maintenance (including maintenance in emergency situations) can significantly reduce errors. In healthcare, skilled doctors do not need to physically provide support in surgery, minimising their need to travel.	✓	✓	✓
Retail	XR enables visualisation of products and virtual shops, which can reduce the number of trips customers make to the physical shop. It has the potential to reduce the size or number of physical shops, reducing energy consumption.		✓	
Design and prototyping	Digital prototypes can be modified in an XR environment through XR collaborative design applications, minimising the use of (and in some instances completely avoiding) raw resources during the prototyping phase and reducing the overall number of (physical) prototypes.	✓		✓
Training	Training in certain professions (e.g. firefighting) requires a lot of material. XR can reduce the negative impact of such training on the environment by reducing the amount of materials used. XR also enables some training to be conducted remotely. Surgery, first aid and other medical training courses can be carried out and repeated without the need for expensive models.	✓	✓	
Remote collaboration	Business meetings and collaborative applications in VR/AR can provide users with efficient ways to collaborate remotely, reducing the need to travel and in turn reducing CO2 emissions in the transport sector. However, the positive environmental impacts of this type of XR are still not fully proven and will require additional uptake.	✓	✓	
Construction & Architecture	Architects are increasingly making use of VR to better understand how to make their buildings as environmentally efficient as possible. For example, through VR they can assess how best to utilise natural light, reducing dependency on artificial light sources. In addition, through Building Information Modelling architects can easily bring their design 'to life' without the use of material maquettes and mock-ups, and virtually visit and collaborate with other professionals. This would reduce visits to physical sites.	✓	✓	✓

42 XR Impact, Be Earth
43 XMReality

+ Awareness raising

XR Impact

XR Impact created Be Earth #13 – an immersive experience that transports the viewer to the Amazon rainforest where climate change is having a clear impact. It invites participants to embody earth and learn more about climate change, to take action and personal responsibility to help end global warming.

+ Remote maintenance

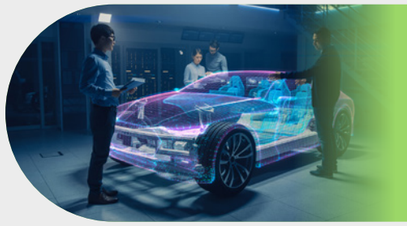
XMReality Remote Guidance[45] (Sweden)

Remote Guidance enables users to talk, display, gesticulate, demonstrate, draw, write, point and show pictures and drawings. Some users of Remote Guidance reduced the amount of travel by about 50%.

+ Retail

IKEA[46] (Sweden)

IKEA Place uses AR to allow its users to visualise how furniture will look in their own home before reserving it. Consumers can then reserve items via the app which can potentially reduce the number of trips they will need to make to the physical shop.



+ Design and prototyping

SEAT[47] (Spain)

SEAT's use of VR led to a 50% reduction in the number of prototypes needed to be made physically prior to launching a new model. Using VR also lowered SEAT's production time by 30%.

+ Training

FLAIM Systems[48] (Australia)

The FLAIM Systems simulator recreates the full firefighter experience, from the visual scenario to the likely temperature. Using VR technology reduces the environmental impact of firefighter training by enabling people to train without discharging foam into the environment, creating smoke or using water.

+ Remote collaboration

Glue Collaboration[49] (Finland)

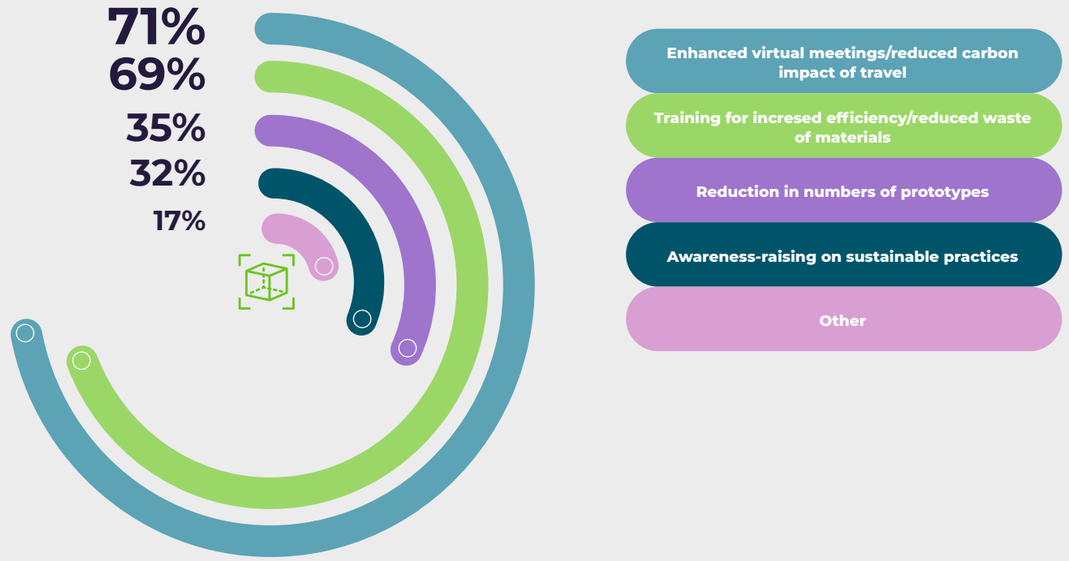
KLM Royal Dutch Airlines is using Glue, a 3D virtual space for remote collaboration in which participants can use features such as whiteboards, share videos, web pages and presentations as they would in the physical world. In a pre-COVID-19 era, KLM routinely flew employees to their offices around Europe for meetings. With VR telepresence, the carbon footprint is reduced significantly.

44 XR Impact
45 XMReality
46 Ikea

47 SEAT (2018), *How SEAT applies VR.*, available here.
48 FLAIM
49 Glue Platform

In the Ecorys XR industry survey conducted amongst XR providers, almost 60% of respondents answered that their product or service aims at improving its users' sustainability, which demonstrates the potential to use XR to make certain processes and/or products more environmentally friendly. The figure below shows the ways in which XR improves environmental sustainability according to respondents.

We asked European XR companies with XR solutions to environmental sustainability, how their product or service contributes to improving its users' sustainability. Here is what they answered:



Source: Ecorys (2020), *XR Industry Survey*, see methodological note in Annex II.

SEAT's use of VR led to a 50% reduction of prototypes

Digital prototypes can be modified in an XR environment, minimising (and in some cases avoiding) the use of raw resources during the prototyping phase and reducing the number of physical prototypes overall. SEAT – a Spanish car manufacturer – has declared that VR plays an essential role in the development of its cars. Traditionally, the process of designing cars involved several steps including the construction of many physical models. A lot of time was required to adequately express different design ideas on the assets. Meanwhile, if a design was rejected along the way, the designers would have to start again from scratch. Therefore, a lot of work was undertaken in vain before the company reached the final product, and at great cost. On the other hand, virtual 3D models can be used to understand, and even feel, both the exterior and interior of the product before it physically exists. VR is used to plan how the new vehicle might be constructed once it becomes a production line reality. As a result, VR has enabled SEAT to half the number of prototypes needed prior to launching a new model. It has also lowered SEAT's production time by 30%.

5.3 Weighing costs and benefits

While XR's potential to contribute to environmental sustainability has been clearly demonstrated, it is important to remember that it may also have some negative impacts on the environment (at least in the short run) if not addressed carefully. For example:

- The production of AR/VR hardware relies on natural resources. Until now, most of the plastic used in production has been made from non-renewable fossil fuels. Alternative resources may help to mitigate this in the future.

- VR and AR require more computing and consequently, until now, more electric power than more traditional methods at every stage of production and delivery. According to some studies, VR computers need to be seven times more powerful than regular desktops to run smoothly[50] which could be reduced, at least to some extent, by technological progress.

- Like most digital technologies, the demand for XR is not naturally bounded, which means that we can expect continuous demand for better resolution, more simulated detail and faster response times, encouraging producers to develop more powerful, energy-consuming hardware sets that can accommodate more sophisticated XR software/content. While this is not an issue solely related to XR hardware, it may have negative environmental impacts to consider, and hardware developers may need to think about solutions to allow for upgrades without full replacements to mitigate such impacts.

In order to assess XR's contribution to more sustainable production, consumption and service delivery, the benefits of it, such as reduced resources or reduced travel, have to be compared against potential costs in terms of energy consumption and resources used to produce the necessary hardware. While thorough research is needed to draw clear conclusions on XR's potential contribution to sustainability, the analysis below divides the application areas into three categories based on their potential environmental benefits that would outweigh the costs:

High potential

- Design and prototyping: The benefits here are much higher for complex, high-tech and material-intensive prototypes, but also apply to smaller consumer goods. As long as the use of XR replaces physical prototypes and reduces mistakes in the design phases, the benefits can significantly outweigh the costs.

- Construction and architecture: From conception to construction and interior design, the number of complex interactions of professionals and the potential for substitution (of material and processes), make the potential positive impact on sustainability quite significant. There is certainly a correlation between the number of uses and the complexity of projects but in most cases the benefits can outweigh the costs.

Critical mass required

- Remote collaboration, maintenance and training: In all three cases a big proportion of their sustainability is a result of reduced travel. While this can be significant, it all comes down to the numbers. The main question is, 'how often and how many users would benefit from these remote solutions instead of travelling to conduct the same task?' This does not mean that a single VR training session would not be beneficial, but the effect would be less sizeable. Thus, these solutions are more relevant to large organisations with staff working from different locations or organisations frequently needing to use these solutions.

Low potential/unclear

- Awareness raising: While XR has the potential to generate empathy and promote sustainable behaviour, there is little evidence as to whether this leads to different levels of behavioural change compared to other awareness-raising methods.

- Retail: XR visualisation possibilities and e-commerce applications could create a positive trend. However, it is unclear whether this would be higher compared to other e-commerce shops and visualisation methods. In addition, retail XR could affect all consumers and while it is unclear if this use solely leads to a positive impact, assuming that consumers already have access to hardware (e.g. smartphones), it could be more significant.

The sustainability of the applications discussed in this chapter is not guaranteed, but their potential is evident. In some cases, increased awareness and additional effort can ensure that the use of XR is sustainable. For instance, while in many cases the sustainability aspect is more relevant to larger organisations or more complex production processes, new models of shared XR solutions could access more players (e.g. smaller organisations) in a sustainable way.

XR needs to become mainstream or at least more popular to have a positive effect on the environment. To achieve this, more comfortable and affordable hardware is required, especially for the applications (mentioned above) that need to reach a large number of people in order to notice a reduced carbon footprint.

Furthermore, XR technology development hardware tends to become obsolete rather quickly, as new technologies and software require additional computing power and enhanced headsets. The stakeholders we have contacted have not reached a consensus as to whether the average lifespan of pieces of hardware can be expected to increase in the following years. If it did increase, it could certainly be considered a positive factor as it would decrease the carbon footprint of XR technology.

Moreover, companies could try to use sustainable materials for their hardware. While this is not always possible, we have come across a few good examples. For instance, Wizdish VR treadmills are 100% recyclable in both their components and packaging, as they are made of polymers, and are designed to last a relatively long time.

Companies could also reduce the number of hardware pieces that need producing. Currently, the XR software ecosystem is not unified and software developers do not have access to the specific tools required for each platform. Therefore, interoperability is not ensured. Standardisation could result not only in the production of less hardware but also in optimised software, leading to additional energy savings.

5.4 Making XR more sustainable

The main challenges associated with applying XR solutions (identified above) are lack of incentives to invest in them solely for the sake of improving environmental sustainability and the need to buy and use energy-intensive hardware.

While some funding opportunities under the European Green Deal and EU digital strategy, Shaping Europe's digital future, intertwine digital technologies with good environmental practices, there is no specific mention of XR which could help to advertise its sustainability potential. At EU level, the Eco-design Directive entails EU-level rules on the environmental performance of products including ICT. These requirements are complemented by the Energy Labelling Regulation which indicates mandatory labelling product requirements. However, this framework does not dive into the specificities of individual technologies,

50 Sustainable Virtual Design (2016), *Virtual Reality and Sustainability I – Introduction*, available here.

including XR. Specific grants could be offered to firms interested in improving their sustainability with XR technologies. In addition, more research could provide clarity on how to unleash the real benefits from the use, and consequently the impact, of financial incentives targeting more environmentally friendly XR.

The COVID-19 pandemic has also created the conditions for XR to have an increased positive impact. Travel restrictions mean that the demand for virtual meetings[51] and remote collaboration has increased. Similarly, companies offering remote maintenance with the use of AR saw a dramatic increase in the use of their solutions. In general, the pandemic is also affecting people's behaviour, including changes that may continue after the crisis. For instance, limited travel should push XR in areas such as **remote collaboration** and **remote maintenance** into the early-adopter phase faster. Additionally, European companies that owned a relevant XR solution before the pandemic had the chance to see their product become more popular earlier than expected[52].

In terms of industry, new innovative business models and applications could emerge to ensure more sustainable use of XR. Ensuring the technology develops in an ethical and sustainable way and that potential new applications emerge is the joint responsibility of the industry and policymakers.

XR tourism: A potential case for the future

XR applications in the tourism sector already exist, enhancing tourists' experiences through AR solutions, providing real-time information on traffic and hotels or displaying contextual insights based on the user's location, as well as VR solutions such as virtual tours. Potential future VR experiences can improve the sustainability as well as the inclusiveness of tourism. The potential to recreate a real-world location in a photorealistic way could create entirely new business models in leisure and cultural tourism. While it is unrealistic to believe that such experiences would substitute physical travel, they could improve accessibility to (virtual) cultural sites (i.e. for people with disabilities) as well as substitute certain types of tourism, such as study and educational visits to historical or cultural sites.

51 At the moment, these are mostly conducted by standard telecommunication tools but could see an increased role of XR technologies.
52 Examples include Engage, Bizzlogic and Virbella.

6 A fast-growing need for XR jobs and skills

XR has the potential to directly create employment for up to 860,000 people by 2025. As the number XR jobs increases, technical roles such as software developers and engineers, as well as creative and business skills in relation to XR, will be highly sought after. The challenge Europe will face is meeting the demand.

6.1 Policy background and employment trends

A Europe fit for the digital age is at the core of the EU's agenda, acknowledged as one of the main priorities and pillars of the European Commission. The EU aims to boost digital literacy and ensure Europe is up to speed with digital skills for both young people and adults. Thus, digital skills are at the heart of the European Digital Strategy and the new European Skills Agenda, as the European Commission is promoting various initiatives aimed at increasing training on digital skills, harnessing digital technologies for learning and anticipating and analysing skills needs.

The EU is calling on public and private organisations to join forces in a collective action to upskill and reskill people in Europe (e.g. the Digital Skills and Jobs Coalition[55] and the newly launched Pact for Skills[56]), along with making resources dedicated to advanced digital skills available (e.g. Digital Europe Programme[57]).

In this context, XR technologies are expected to have a profound impact on the labour market over the coming years, creating **new jobs** and increasingly promoting a multitude of **new and cross-disciplinary digital skills**. This would be a direct result not only of implementing XR technologies, deploying and making content for them, but also indirectly by reskilling people, allowing them to learn physical skills through digital means, such as training, teaching, remote assistance and maintenance.

53 *Shaping Europe's digital future: The European Digital Strategy*, available here.
54 *European Commission (n.d.), European Skills Agenda*, available here.
55 *European Commission (2021), Digital Skills and Jobs Coalition*, available here.
56 *European Commission (n.d.), Pact for Skills*, available here.
57 *European Commission (2021), The Digital Europe Programme*, available here.

Enhancing existing jobs and skills

XR technologies are not only creating new jobs and skills, but they are also completely transforming already existing ways of working. By providing meaningful enhancements to physical experiences, XR technologies have the potential to upskill and augment workers' abilities and companies are successfully deploying XR solutions with enormous benefits in terms of workforces' increased performance, productivity and reduced errors[58].

One of the most common examples is the industrial use of AR smart glasses in manufacturing or maintenance environments that overlay computer-generated video, text or images information onto physical objects (e.g. step-by-step repair instructions). Such a visual guide has proved to be capable of increasing productivity by making workers more skilled and efficient[59].

Via AR glasses and MR interface, operators can see decision-making instructions that will guide them through the most complex control operation, replacing paper instructions and greatly improving efficiency of processes.

VR training scenarios are being deployed in different sectors proving that great ROI[60] and VR solutions are also being tested to help the unemployed to choose their first or a new occupation by exploring jobs and training in unfamiliar situations within a safe setting[61].

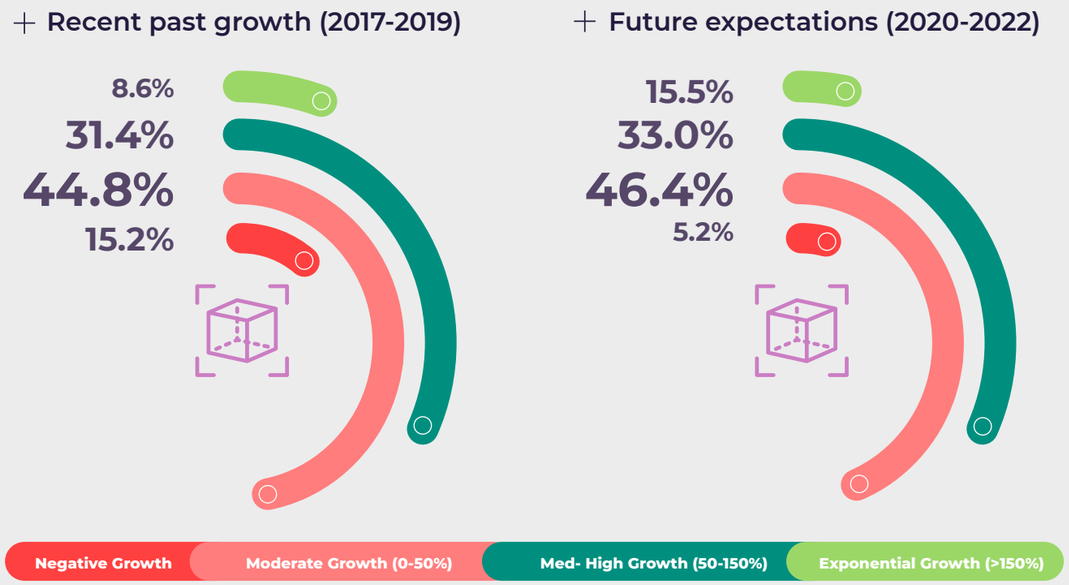
The impact that the adoption of XR technologies is expected to have on employment is massive, as shown by our estimates which indicate that 1.2 to 2.4 million new jobs will be directly or indirectly created in Europe by 2025. Globally, some estimates indicate that more than 23 million jobs will be enhanced by the adoption of these technologies by 2030, a substantial increase from the estimated 800,000 today[62].

Recent trends and growth expectations from companies in the sector predict a successful future for XR employment, which is on the rise.

Most of the surveyed XR companies **foresee a moderate to exponential growth in the next three years**. Although the research was carried out during the COVID-19 pandemic, partially internalising possible impacts, the future net effects on XR employment and more broadly on the XR industry are not clear-cut and do not draw consensus amongst stakeholders, as also shown in the recent XR4ALL COVID-19 survey[63].

58 IBM (2020), *AR and VR in the workplace*, available here.
59 Abraham and Annunziata (2020), *Augmented reality is already improving worker performance*, available here.
60 Rogers (2019), *How VR, AR and MR are making a positive impact on enterprise*, available here.
61 NTNU (n.d.), Virtual internship, available here.
62 PWC (2019), *Seeing is believing*, available here.
63 XR4ALL (2020), *XR4ALL COVID-19 Survey: Impact on XR in Europe*, available here.

We asked European XR companies about their recent employment's growth and expectations for future growth. Here is what they answered:

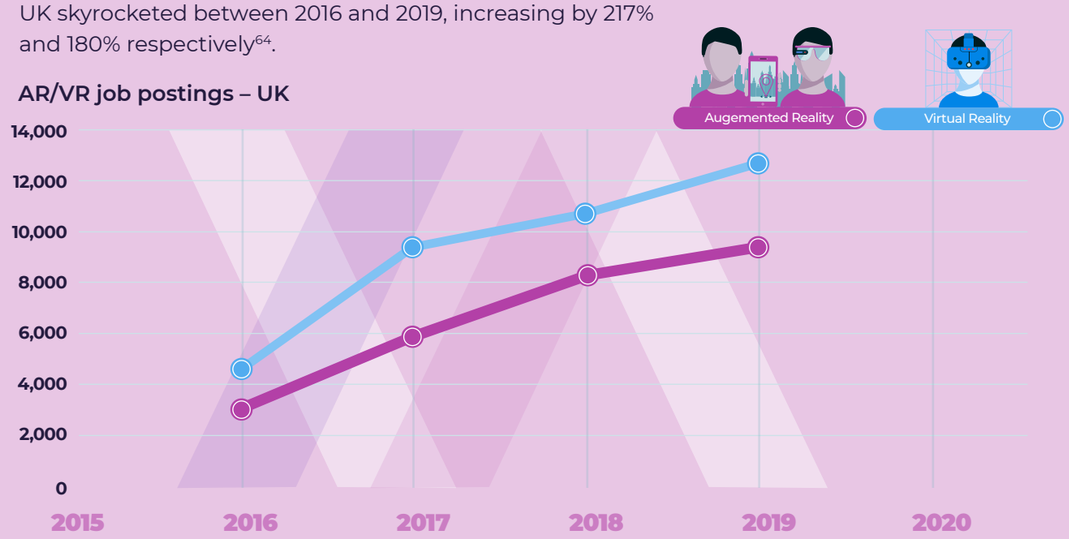


Source: Ecorys (2020), *XR Industry Survey*, see methodological note in Annex II.

Insights from the UK example

Being one of the main and more dynamic markets in the European XR landscape, the UK offers insight into the recent evolution of the XR job market. Jobs related to AR and VR in the UK skyrocketed between 2016 and 2019, increasing by 217% and 180% respectively[64].

AR/VR job postings – UK



Source: Ecorys, based on Emsi data

64 Data were collected by conducting data scraping through a database of around 14 million individual worker profiles in the UK, filtering per VR, AR and XR skills attributes. See methodological note in Annex II.

6.2 Trends in XR industry workforce composition

Where will the XR jobs of the future be concentrated? What are the implications of this for skill needs?

An appropriately **skilled workforce is essential for companies to find employees and grow**. XR companies need **talent that can approach XR from different perspectives** and rely on teams that can work across a wide range of technical, creative, social and business disciplines. In fact, we cannot look at XR technologies from a technical standpoint alone as it will not suffice. While technical upskilling of the labour force is needed to cope with the constant evolution of XR technologies, creativity is equally important, bringing creative ideas and technologies to life, as well as business and managerial skills.

Involving psychologists and representatives of social science and humanities will also be a key factor for success, creating cross-disciplinary figures that can bridge the gap between customers and developers. This will reduce the distance between them by blending different perspectives together based on a common vocabulary. New skills and job positions will need to be created from scratch which will call for research and education to closely interact and work with the industry to create a specific and continuously up-to-date body of knowledge, bringing down current barriers.

Currently, the landscape of job profiles sought on the XR market is very complex, reflecting the wide range of perspectives and angles from which XR technologies are developed. On the **technical side**, typical AR and VR teams feature various key profiles, such as **software developers and engineers**, which are some of the most sought-after profiles on the market. Qualifications generally span from computer science (including programming languages such as C, C++, Java, Python and operating systems) to software engineering or an equivalent, configuration, and test management and defect tracking tools.

Looking more closely at profiles on the **creative side, 3D artists** are quickly emerging as key figures in the future of the industry, responsible for all kinds of visual effects, from models to textures and 3D simulation. Similarly, **User experience (UX)/User interface (UI) designers** are also in very high demand nowadays, as designing human-computer interactions and user interfaces for machines and software is key. The user experience is crucial and must be intuitive. Designing an experience that is natural, comfortable, fun, straightforward and not overwhelming is very important, especially for those that are fully immersive. Thus, experience in spatial design and working with unity, proficiency, visual design tools and pre-visualisation/prototyping tools is essential.

However, the various software and technical prerequisites are not the only skills needed. **Human factors and social science** need to be involved in order to understand how people interact with the devices, making their design more natural for the user and relevant to the sector. It also improves the technologies' ability to invoke emotion. Interdisciplinary expertise is required when it comes to ethical guidelines, privacy and security.

XR teams must also include people with business-related skills, encompassing **excellent communication skills** and the ability to grasp **market trends and interests**, as well as customers' ambitions and intentions. Experienced **project managers** with managerial and business skills, sound XR market knowledge and vision are also needed to effectively lead XR projects in all of their dimensions.

Top 10

AR/VR job titles and skills sought on the UK market (based on job postings activity)

Data on jobs from advertised vacancies, collected from the UK market, show a clear dominance of software developers/engineers with programming languages and computer science skills for both AR and VR. Nonetheless, creative and business roles are also in high demand, as XR impacts the whole company value chain and companies' processes, hence the skills involved and needed.

Top 10 jobs

Augemented Reality

1. C/C++ Developers
2. Software Engineers
3. Multimedia Developers
4. 3D Artists
5. Front-End Developers
6. Android Developers
7. Mobile Software Engineers
8. JavaScript Developers
9. Game Engineers
10. Research Engineers

Other: virtualisation engineers, graphic software engineers, PHP developers, senior developers, UI designers, project managers, digital designers, IOS developers, business development managers, web developers, Python developers, graphic designers, computer scientists, remote developers, mechanical engineers

Virtual Reality

1. C/C++ Developers
2. Software Engineers
3. Virtualisation Engineers
4. Personal Trainers
5. Project Managers (Management)
6. Events Supervisors
7. 3D Artists
8. Multimedia Developers
9. Front-End Developers
10. Game Engineers

Other: event managers, graphic software engineers, JavaScript developers, PHP developers, Android developers, UI designers, mobile software engineers, senior developers, business analysts, business development managers, graphic designers, web developers, IOS developers, computer aided design (CAD) technicians, auctioneers

Source: Ecorys, based on Emsi data

Businesses looking to hire XR developers look for a combination of prominent skills such as software programming and languages (e.g. Java and C/C++, Python), experience in 3D design, video or sound production, proficiency in creating XR content and UI/UX, and knowledge of various device specifications and hardware/software.

Top 10 skills

Augemented Reality

1. C++ (Programming Language)
2. Software Engin C# (Programming Language)
3. Agile Software Development
4. JavaScript (Programming Language)
5. Software Engineering
6. Python (Programming Language)
7. Machine Learning
8. Software Development
9. User Experience
10. Java (Programming Language)

Other: computer vision, animations, cascading style sheets (CSS), computer science, IoT, Unity engine, AI, prototyping, user interface, application programming interface, hypertext markup language (HTML), Amazon web services, Adobe Photoshop, algorithms, front end (software engineering)

Virtual Reality

1. C++ (Programming Language)
2. C# (Programming Language)
3. Agile Software Development
4. JavaScript (Programming Language)
5. Project Managers (Management)
6. User Experience
7. Software Engineering
8. Python (Programming Language)
9. Animations
10. Machine Learning

Other: Java (programming language), cascading style sheets (CSS), Unity engine, AI, application programming interface, Adobe Photoshop, computer science, IoT, Unreal engine, hypertext markup language (HTML), prototyping, new product development, Linux, user interface, Amazon web services

Source: Ecorys, based on Emsi data

How are these skills perceived amongst XR companies? What skills do companies value most when selecting XR employees? How will this change in the future?

A diverse picture emerges when we look at the answers to these questions. The availability of skills varies, but the companies and experts interviewed do not believe there is widespread availability of the key skills needed for XR on the market currently. The perceived availability of skills provides an insightful overview of the state of play of the XR labour market, but this cannot be considered alone. It needs to be interpreted in conjunction with the relative importance of the skills to businesses. The research shows that a large number of skills are considered highly important, pointing towards a mosaic of skills, which indicates the complexity of the XR landscape and the needs of multidisciplinary teams.

Availability and importance of relevant skills

Skills	Current availability	Current importance	Future importance
Technical			
Coding languages (e.g. C#, C++, Java)	**Moderate**		
Knowledge of XR platforms (e.g. Unity)	**Moderate**		
Technical troubleshooting in XR	**Low**		
Hardware development	**Very low**		
Configuration and Test Management	**Very low**		
Search Engine Optimisation techniques	**Moderate**		
Creative			
User Design/Interface skills	**Moderate to low**		
3D modelling	**Moderate to high**		
Artistic skills (e.g. storytelling, visualisation)	**Moderate**		
Business			
Customer-related soft skills	**Moderate to low**		
Project management skills	**Moderate**		
XR market knowledge	**Low**		
Knowledge of legal framework	**Low**		

Lower shares of stakeholders indicating high importance — **Higher shares of stakeholders indicating high importance**

Source: Ecorys, based on stakeholders survey and expert interviews

We cannot assume that in the coming years XR experiences will be created in the same way as today. The methods for creating experiences will change over time, thanks to continuous innovation which will challenge and improve existing methods and processes. Skills and competences will have to adapt quickly, in order to avoid potential gaps.

Potential future skill gaps

Skills	Potential future gap
Technical	
Coding languages (e.g. C#, C++, Java)	
Knowledge of XR platforms (e.g. Unity)	
Technical troubleshooting in XR	
Hardware development	
Configuration and Test Management	
Search Engine Optimisation techniques	
Creative	
User Design/Interface skills	
Artistic skills (e.g. storytelling, visualisation)	
3D modelling	
Business	
Customer-related soft skills	
XR market knowledge	
Knowledge of legal framework	
Project management skills	

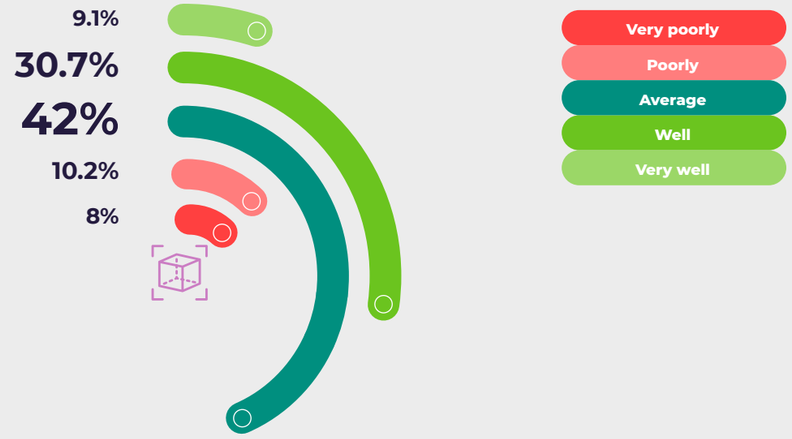
Larger discrepancy between perceived importance and availability — Smaller discrepancy between perceived importance and availability

Source: Ecorys based on stakeholders' survey and expert interviews

6.3 A look towards the future

The fast-paced growth of XR technologies, combined with their relative novelty, may generate an equally rapid skill gap that could widen if left unaddressed. The sector is still in an experimental research and development phase in terms of technological opportunities and constraints, business models, job roles and operational skills. In order to grasp the opportunities for growth and become a global leader in XR technology, Europe will need to keep promoting relevant skills, in terms of education, training and professional development.

We asked European XR companies how well their national education system promotes the skills required for the XR workforce. Here is what they answered:



Source: Ecorys (2020), XR Industry Survey, see methodological note in Annex II.

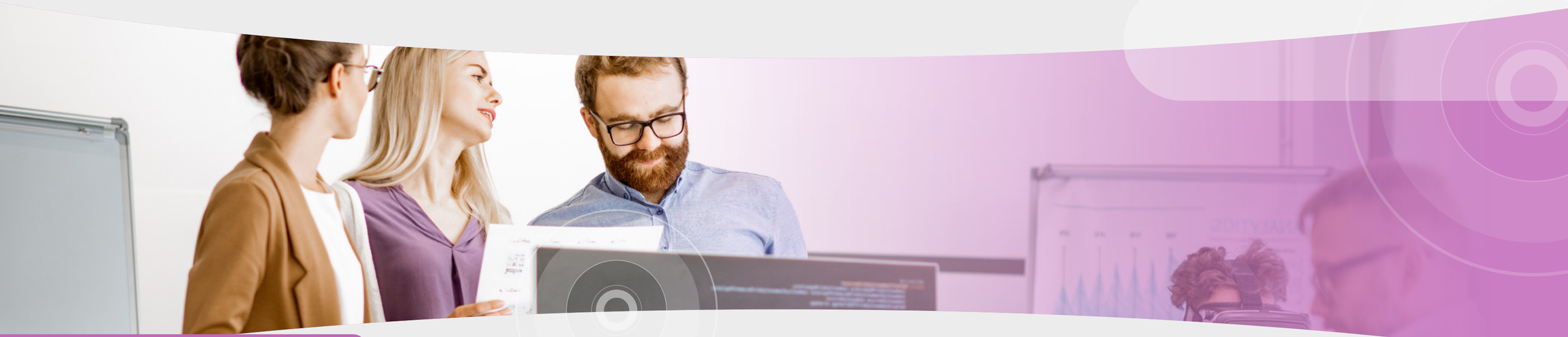
Roughly 40% of the consulted stakeholders indicated that their country's education system was 'good' or 'very good' at promoting relevant XR skills. **New programmes dedicated entirely to XR design and development are steadily flourishing in Europe**, making courses and programmes more mature and relevant to the latest technological developments. Universities are already teaching developers to approach XR from different perspectives, including art, design and industrial production, responding to the challenge of designing courses that blend the necessary range of disciplines and appropriate levels of science and arts.

However, in order to thrive, the European XR ecosystem will have to focus on some of the pressing **challenges that still exist in the sector:**

- **Skill shortages:** skills needed for success and growth are complex, cross-disciplinary and in some cases in short supply, especially for SMEs. Some of the most interesting concepts in XR combine immersive technologies with other high-growth specialisms/technologies, such as AI and ML. This calls for people to have a deep cross-disciplinary skillset, exacerbating the risk of talent drought.
- **Improve cooperation between research/academia and businesses:** despite the notable achievements of university research, there is still distance between education systems and industry/market needs. Bridging this gap is essential to counter the risk of rapidly obsolete programmes and courses, making sure they remain up to date and reflect advancements in terms of technological opportunities, business models and skills. For instance, projects are being put in place to implement the Industry 4.0 concept in companies through academia/SME collaboration[65], and many successful XR start-ups are born as spin-offs of universities or research centres[66].

65 Such as the Italian 'Lighthouse Plant' project; additional information here.
66 For instance, Ultraleap, Imec Research and Vologrames.

- **Awareness and accessibility:** these are still limited for the general audience and need improving. The proportion of people that are familiar with or have access to these technologies is rather low and for most of them it is their first experience with XR. Increasing the use of XR technologies as a teaching tool in universities/schools could help to bridge the gap, improving the exposure of younger generations to XR and in turn positively affecting the attractiveness of these technologies.



Pedagogical uses of XR

While this chapter focuses on the skills the XR industry needs to develop further, XR also has great potential to enhance pedagogical methods by introducing innovations. The use of XR can expand the range of activities through which students can gain hands-on experience, enabling them to go beyond abstract knowledge and supporting skills-based teaching and learning.

Given their capability to boost learning potential and personalise learning experiences, AR and VR technologies are already being used in different scenarios. For instance, in many cases XR is used to implement language courses in schools[67] and further solutions are being already tested in different education fields, such as medical and chemistry[68]. The XR4ALL initiative also created a 'special interest group' to discuss how immersive technologies influence teaching methodologies and pedagogies[69].

VR can also play an important role in promoting distance learning and the inclusiveness of education by bringing immersive experiences to a large number of students that otherwise would not have the opportunity to travel to the location. It is achieving this by tackling one of online learning's biggest problems – a lack of interaction[70].

67 See for example XR ERA (2020), *Immersive language learning*, available here.

68 Pomerantz J. (2019), *XR for teaching and learning*, available here.

69 XR4ALL (2020), *VR/AR for learning and training*, available here.

70 Stanford Business School (2016), From virtual to reality, online LEAD program exceeded expectations, available here.

- **Competition for talent with other industries:** competition for talent is fierce not only amongst (semi-) immersive experience producers (e.g. gaming, movies) but also more traditional engineering disciplines such as automotive, due to the transferable expertise in key areas (e.g. Real Time Game Engines, UX/UI design etc.).

- **Inclusiveness:** this should be ensured for all. For instance, although there are already several prominent female figures in the XR industry, gender balance is still an issue. Additionally, studies suggest that current VR headsets could be more likely to cause motion sickness in women due to flaws in design . Such barriers must be addressed sooner rather than later so that the industry can fully transition to a space of equal, merit-based opportunities.

71 Stanney, Fidopiastis and Foster (2020), *Virtual Reality is sexist: But it does not have to be*, available here.

7 Shaping Europe's XR future

Since Ecorys' 2016 VR report, the European XR industry has evolved and maintained a leading role globally in software and content production. The following improvements could be made to further strengthen this leading position:

- Using XR as a response to COVID-19 to mitigate its impacts;
- Ensuring education and training corresponds to the industry's increasing needs;
- Nourishing the XR ecosystem through organisations such as digital innovation hubs;
- Raising awareness around XR and its potential for Europe;
- Creating funding, financing and investment opportunities.

7.1 The European XR industry is flourishing...

This report has explored the strong potential of the XR industry in Europe. This is demonstrated by the rapid developments over the past five years and confirmed by estimates of the industry's growth over the coming years. While Europe is not expected to be the epicentre of device manufacturing, it has what it takes to be a global leader when it comes to XR software and content development.

Strengths

- A maturing XR industry with strong software and content creation;
- A creative culture with high innovation potential;
- A well-distributed ecosystem with several regional hubs focusing on different application areas;
- Europe's leading role in several industries and service sectors where XR demand is trending upwards;
- GDPR: a state-of-the-art regulatory framework on data privacy and a leading position setting global standards for regulating the digital economy.

Weaknesses

- Lack of private funding opportunities for XR innovation, in particular risk funding;
- Lack of indigenous 'big players', i.e. hardware manufacturers;
- Scattered approach to XR development;
- Lack of entrepreneur mentality in European landscape and of a solvency framework enabling risk-taking.

Opportunities

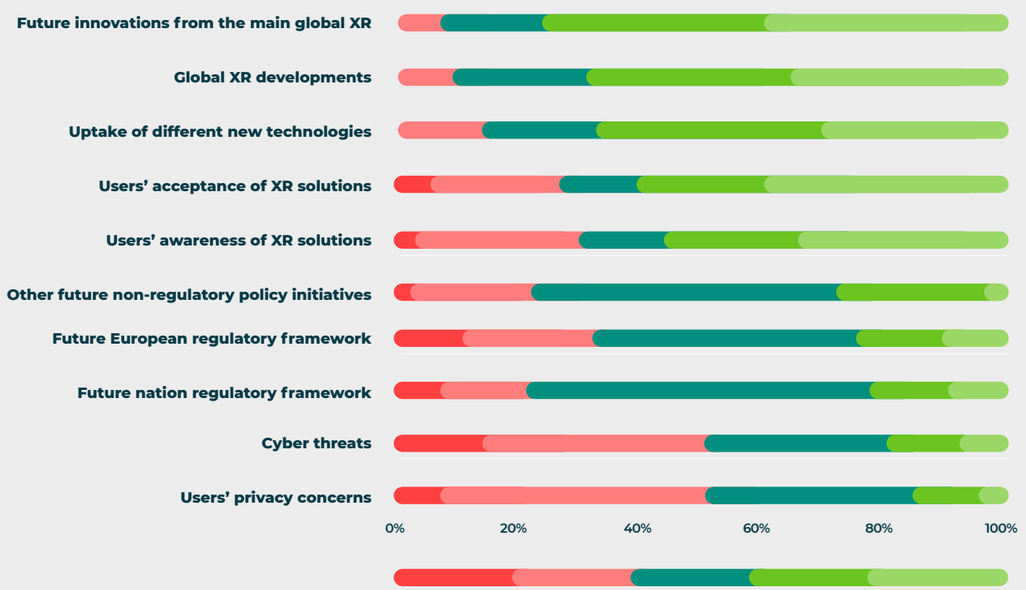
- Old working structures deteriorating due to COVID-19
- Favourable policy agenda focusing on digitalisation and greening of the European economy;
- Europe's focus on green economy and the untapped potential of XR for sustainability.

Threats

- Lack of skilled workforce;
- Economic slowdown due to the COVID-19 crisis;
- Social acceptance of new technologies linked to privacy, safety and security concerns.

There is no doubt that significant developments in the XR global and European landscape will occur until 2025. New players will enter the market, revolutionary hardware will be introduced, new business models will emerge and business and production processes will be enhanced through innovative use of XR. Our Strengths weaknesses opportunities threats (SWOT) analysis indicates that the **European XR industry is in a good position to accommodate these changes**, however, in its current shape, the XR industry could use some improvements to grasp future opportunities, mitigate threats and, where possible, address weaknesses.

We asked European XR companies if they perceive the following aspects as threats or opportunities. Here is what they answered:



7.2 … but there is room for improvement

Throughout different consultations (interviews, surveys and workshops), in this study one of the key issues discussed was what can be done not only to support the industry, but to support its development towards a sustainable, ethical, inclusive and beneficial expansion over the coming years. The research showed that a coordinated approach from all stakeholders (i.e. industry representatives, associations, policymakers) would be optimal.

The following areas with opportunities for improvement were identified:

- **XR as a response to COVID-19 impacts:** the economic and societal responses to the COVID-19 pandemic have boosted the use of digital solutions and consequently skills across all age groups and types of work. This has not entirely materialised yet in a significant way for XR, especially for smaller companies. More advanced XR solutions, with the potential to overcome challenges posed by the pandemic, have not yet been implemented. Opportunities to discuss, demonstrate and develop these solutions quickly could resolve pressing issues. Hackathons, dedicated investment opportunities and other initiatives supporting relevant XR applications in the short term could be considered. In the long term, XR solutions could accelerate digital transformation of Europe's industry to enhance future resilience to pandemics.

Education and training: given the expected growth of the sector and potentially increasing demand for (high-skilled and well-paid) jobs, ensuring a pool of available talent equipped with the right skills is essential. In most digital sectors continuous labour market intelligence on skills and talent demand forecasts are crucial to develop a talent pipeline. Matchmaking events at universities and companies can prevent a skill mismatch.

Skill gaps could be further avoided by:

- Incorporating XR in university courses such as computer science, computer engineering and programming or providing opportunities to specialise and boost relevant skills of the future workforce. Digital and XR literacy modules would also be relevant to complementary creative fields such as media production, art and design.

- Introducing XR technologies to schools and education institutions as an education tool. This would utilise the knowledge transfer potential of the technologies and increase the familiarity of young people with XR.

- Using vocational training (reskilling) and professional training (upskilling) opportunities to address the growing job demand in the shorter term.

- Improving the diversity of the XR workforce by promoting the participation of different groups such as women.

Nourishing the ecosystem: the European XR ecosystem is diverse. Bringing different members of the ecosystem together has been achieved successfully through events and communities. Increasing these initiatives will build stronger collaborations across hubs and borders and create synergies. Ensuring the continuity of such initiatives and, where relevant, initiating new ones (e.g. linking specific types of players such as venture capitalists and businesses) as well as helping to identify and support start-ups and smaller players will help to strengthen the XR ecosystem. Digital innovation hubs, incubators, accelerators and other supporting structures targeting XR start-ups and companies have been key to developing hubs throughout Europe. More public-private partnerships with similar missions or increased support to the existing ones would boost XR industry's growth.

Raising awareness: XR is starting to become better known amongst consumers and companies. However, it is still widely misunderstood. Its potential could be better advertised by focusing on different uses of XR. Awareness raising could concern any type of XR application and be achieved through demonstrations, exhibitions and roadshows. Targeted awareness raising could focus on:

- Less known or newly introduced innovative XR applications with significant potential benefits (e.g. cost savings, safety);

- Environmentally sustainable, ethical and inclusive uses of XR and XR solutions;

- Building user awareness on safety to tackle hesitation, for instance due to data privacy concerns.

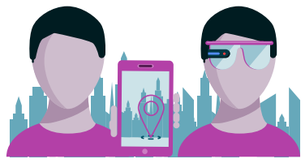
- **Funding, financing and investment opportunities:** in a fast-paced and growing industry such as XR, funding sources must not be omitted from the mix of possible improvements. Targeted funding would be required to speed up the maturity and wide adoption of XR. This refers to large-scale infrastructure funding needs, that is for deploying pan-European 5G networks, financing opportunities and investment motives for innovative XR applications and projects, such as projects with high digital transformation potential or other innovative applications.

These are the key improvements this study identified through consultations and interactions with stakeholders. This study shows that compared to Ecorys' 2016 VR report, several changes occurred, with new companies entering the market and hubs increasing in size and importance, leading to a steady growth of the XR industry in terms of size and areas it covers (ranging from healthcare and manufacturing to entertainment and education). With a growth rate that is expected to increase over the next five years, the XR industry is evolving rapidly and new improvements or solutions may be needed. Thus, additional research on, and monitoring of, the technology's development would be useful to track progress and developments and possible challenges that lie ahead.

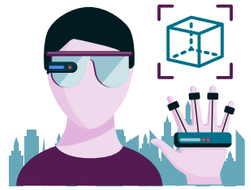
A Annex I – Understanding XR

The three main technologies that make up XR are **augmented reality** (AR), **mixed reality** (MR) and **virtual reality** (VR)[72].

- **Virtual Reality** is an immersive technology that creates a simulated and interactive 3D environment, accessible through different devices. VR consists of an entirely digital environment not necessarily subject to the physical rules of the real world. The spectrum of VR experiences ranges from fully immersive VR, which entails the use of a headset to display the digital world through sight and high-quality 3D sound, stimulating hearing, and an input device (i.e. a controller) to navigate the virtual environment. Additional hardware exists for the purpose of enhancing the immersion or involving additional senses. Examples include haptic gloves (involving touch), virtual rooms (allowing multiple people to experience the same immersive experience) and treadmills (which convert full-body movements in the real world into inputs for the digital world).



- **Augmented Reality** is a technology that, rather than creating a whole new 3D environment, overlays digital information to the real world, which remains at the centre of the overall experience. AR always requires a screen or surface on which the digital information can be projected or shown to be added to the real world. The screen can be that of a smartphone, which captures the real world through its integrated camera and then shows an augmented version of it. Especially for enterprise purposes, though, it is useful for personnel to have both hands free – hence, HMDs have become very popular over time.



- **Mixed Reality** features elements of both AR and VR, adding interactable virtual objects to the information overlaid to the real world. It is similar to AR from a conceptual point of view, as the real world remains central for the user experience. However, entirely virtual objects coexist and interact with real objects and the real environment, as well as with users. The key characteristic of MR is that the synthetic content and the real-world content are able to react to each other in real time[73]. Due to the strong interlinkages with the other two technologies, MR is nuanced in terms of an operational definition, as highlighted in the adjacent box.

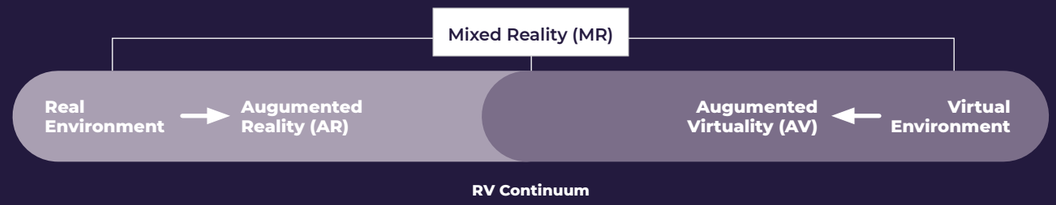
72 Our qualitative definitions are based on XRA (2020), XR at a glance, available here.
73 The Foundry (2017), *VR? AR? MR? Sorry, I'm confused*, available here.

Different definitions of XR

While an understanding of VR is widely accepted, there is an ongoing debate with regards to the definition of the concepts of AR/MR. Notably, there seems to be a difference between a commonly accepted academic definition and the meaning the term has in today's consumer and enterprise market.

The academic definition builds on the concept of the reality-virtuality (RV) continuum, presented below[74].

XR technologies in the reality-virtuality continuum



Here, MR is conceptualised as any technology in which the real and virtual worlds are presented together within a single display. This entails every immersive technology between and excluding the extremes (i.e. the real and VR environments) of the continuum. Therefore, MR acts as a macro-category, including other technologies such as AR[75] and Augmented Virtuality (AV)[76].

According to the market's most common understanding, on the other hand, MR is often considered as an altogether different kind of technology, separate from AR and AV, rather than as an umbrella term which spans between the real and virtual world. This understanding of the term sees MR as a highly interactive AR application, where virtual objects realistically blend into and interact with real objects and/or with the user. This aspect is not part of the academic definition, which was developed in the mid-90s when computer-generated objects were in their infancy.

74 Milgram and Kishino (1994), *A taxonomy of mixed reality visual displays*, available here
75 For another example of AR being seen as a sub-category of MR, see Aryzon (n.d.), *Just to be sure... the differences between Virtual Reality and 2D/3D Augmented Reality!*, available here.
76 AV technologies augment the perception of a virtual environment with real elements. These elements of the real world are generally captured in real time and injected into the virtual environment. The capture of the user's body that is injected into the virtual environment is a well-known example of AV aimed at improving the feeling of embodiment. While useful in conceptual terms, AV is not widely used outside of the academic/technical community.

Virtual Reality

VR entails the creation of a virtual world that users can interact with. Immersive experiences recreate a fully digital world which the user can navigate through with visuals, auditory and haptics necessary to properly interact with digital objects. The main idea behind fully immersive VR is to trick the user's senses sufficiently to eventually stop recognising the difference between the virtual and the real world during use (or at least completely isolate the user from the real world). This goal is better achieved once more human senses are part of the simulation. Current technologies cannot simulate taste and smell, but conceptual technologies are being implemented to replicate different tastes through electrical impulses[77]. The level of immersion in VR can vary, creating an immersion spectrum. Different aspects can play a role in reducing or increasing the level of immersion[78].

Aspect of immersion	Indicators influencing immersiveness
Inclusiveness	Number of signals indicating the presence of devices linked to the physical world (e.g. joysticks, mice, weight of the HMD)
Extensiveness	Number of sensory modalities involved in the simulation (e.g. sight, touch, movement, etc.)
Vividness	Level of fidelity of the image or of the audio; display resolution; level of realism of the 3D environment
Matching	Presence, absence or extent of motion capture technologies; responsiveness of the visual feedback in relation to the user's movements
Surroundings	Level of the field of view; nature of the device used for immersion

It is possible to categorise VR using a different rationale – not the level of immersion, but rather the **platform** used to create the content and the way this is **distributed**. In this sense, **web-based VR** stands out.

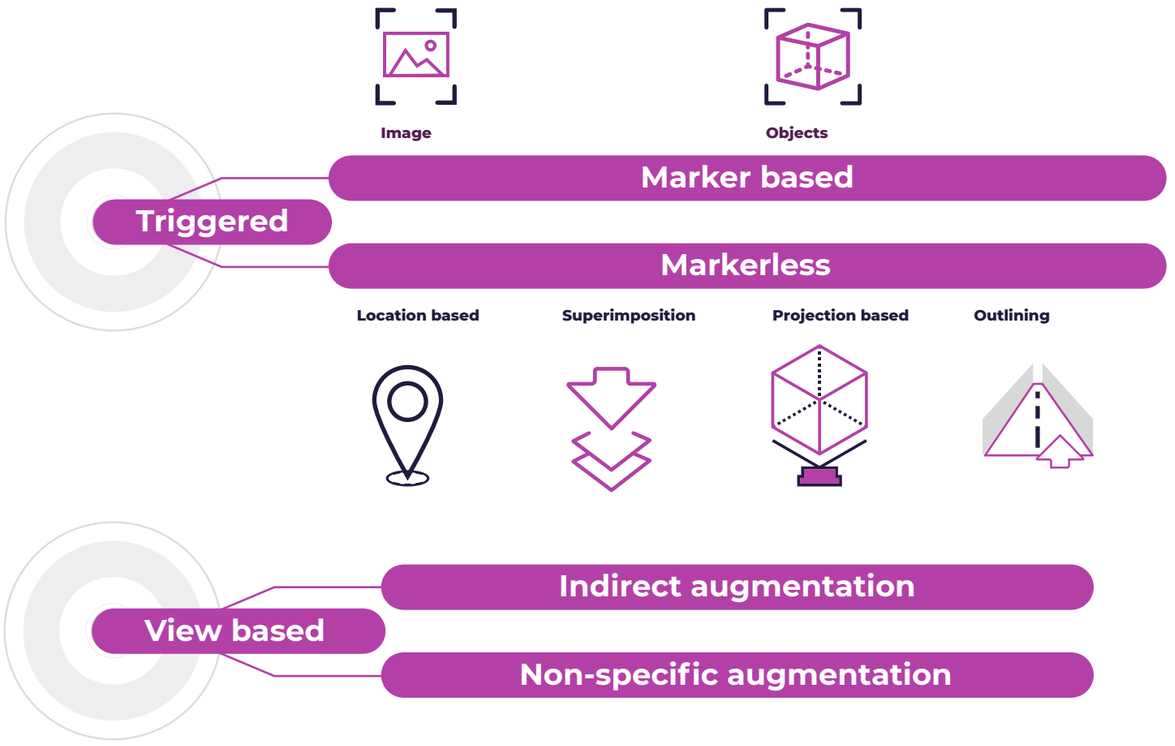
77 As reported in Cyberpulse (2019), *What is fully-immersive VR? – Technology explained*, available here.
78 Miller, H. L. and Bugnariu, N. L. (2016), *Level of immersion in Virtual Environments impacts the ability to assess and teach social skills in autism spectrum disorder*, available here.

Augmented Reality

AR technologies do not create a whole new digital environment for the user to interact with – they superimpose digital information over the physical world, seen through different kinds of displays.

Different typologies of AR are usually distinguished in terms of the technology that allows the augmentation of reality. The figure below shows a possible categorisation[79].

Categorisation of AR, by technology



The first category is known as triggered AR, meaning that a specific characteristic or feature of the physical world initiates (or 'triggers') the augmentation process. Triggered AR can then be marker based or markerless. In the former, a specific marker, which can be an image (e.g. a QR code) or a physical object, needs to be framed for the augmentation to begin. In the latter, there is no need for a specific image cue, as the trigger can be represented by a variety of criteria, such as GPS, compass or accelerometer.

In location-based AR, augmentation is tied to a specific place, which has to be reached by the user. Pokémon! Go is an example of location-based AR. Superimposition AR provides an

79 There is no univocal categorisation of different AR types. We have based this figure mostly on Edwards-Stewart, Hoyt and Reger (2016), *Classifying different types of Augmented Reality technology*, available here, and on G2 (2019), *What is Augmented Reality?*, available here.

alternate view of objects in the physical world by replacing them, partially or fully, with an augmented view. Projection-based AR, which does not work through a mobile device, relies on lights emitted by projectors to display content on a designated surface. Lastly, outlining AR recognises the surroundings of a user and displays information, such as the middle of a driving lane or parking boundaries.

As for triggerless AR, simultaneous localisation and mapping (SLAM) will be key. For a virtual object to correctly find its place in the environment around a user, the quality of the SLAM will make the difference. The device tries to simultaneously localise – find the location of some object/sensor with reference to its surroundings – and map the layout and framework of the environment that it is in. This can be done using a range of algorithms that simultaneously localise and map the objects.

The second category is known as view-based AR, and is used in more static applications. In the case of indirect augmentation, a static view or picture of the physical world is intelligently augmented. In non-specific digital augmentation, a dynamic view of the world is augmented without taking into consideration anything specific that is being viewed.

XR Hardware, software and content

Hardware component			VR	AR	MR
Hardware					
Computing device/processor (e.g. computer, console, smartphone)			✓	✓	✓
Output device examples	**Display**	**HMD headset**	✓	✗	✓
		Monitor	✓	✓	✓
		Smartphone	✓	✓	✓
		Tablet	✗	✓	✓
		Smart glasses	✗	✓	✓
		Head-up display	✗	✓	✗
		Holographic display	✗	✓	✗
		Projection	✓	✓	✓
	Speakers/earphones		✓	✓	✓
	Haptics		✓	✓	✓

Hardware component			VR	AR	MR
Input device examples	**Cameras (2D, 3D, IR etc.)**		✗	✓	✓
	Microphone		✓	✓	✓
	Controllers (Joysticks, Joypads)		✓	✓	✗
	Pen		✓	✗	✗
	Sensors	**Accelerometer**	✓	✓	✓
		Gyroscope	✓	✓	✓
		Magnetometer	✓	✓	✓
		Inertial sensor	✓	✓	✓
		Tactile	✓	✓	✓
		Biosensor	✓	✓	✓
Input and output device examples	**Gloves**		✓	✗	✓
	Bodysuit		✓	✗	✗
	Immersive rooms/CAVE		✓	✗	✗
	Treadmill		✓	✓	✓

Software			
Development platforms	✓	✓	✓
Specific applications software	✓	✓	✓
Content			
Specific applications content	✓	✓	✓

As in most digital technologies XR entails three basic components, which are hardware, software and content.

In terms of hardware, all XR systems require three main components.

A computing device or processor of any kind (e.g. computer, console, smartphone) to process inputs and outputs (i.e. to analyse inputs gathered by sensors, carry out the specific tasks of the given software and display the appropriate content). The amount of computing power can vastly differ depending on the device used, ranging from smartphones and tablets to desktop computers and distributed systems, which are power intensive and can support high-quality graphics.

Output devices to show the result of the interaction with the virtual environment or the virtual objects, according to the technology considered. These devices help simulate human senses and can be divided into three main categories:

- **Displays** allow the visual fruition of digital content. In the case of VR, this can be done through headsets (from advanced VR HMD headsets to cardboard cut-outs that use a smartphone) and monitors, while in the case of AR head-up displays (HUDs), holographic displays, smart glasses, tablets and smartphones may be used. Projection technologies can be used in headsets, or to display information on any kind of surface;
- **Speakers/earphones** engage the hearing sense using traditional or 3D audio. While in VR solutions, audio is required mainly to increase immersion, in AR/MR augmented audio information can be added to real-world audio;
- **Haptic devices** engage the touch sense, which can be recreated through tactile and/or force feedback;

Input devices are what really differentiates one XR experience from another. The main input devices currently on the market include:

- **Cameras** to capture images of the world, to be used as inputs for the computer;
- **Microphones** to record sounds to be stored in digital form;
- **Controllers** (devices with buttons and movement sticks) to allow users to interact with the 3D environment;
- **Sensors** to gather interactions that the user has with the real world, for the processor to combine them with the augmentation process and create a seamless virtual experience;
- **Pens/stylus** (controllers) to provide information on a user's position, orientation and possibly speed to the computer.

Input and output devices (some devices can act simultaneously as both an input and output device):

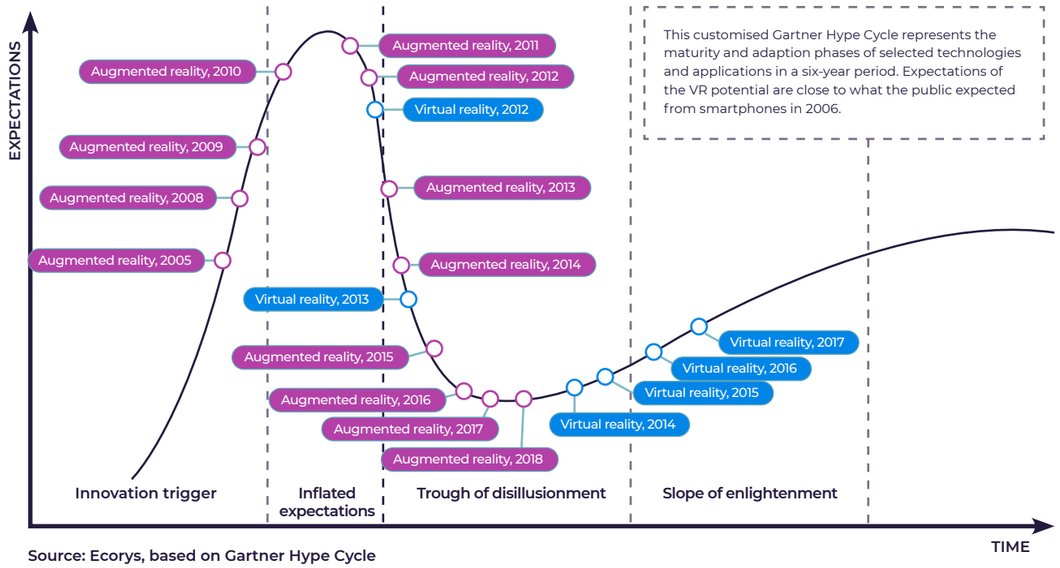
- **Gloves** to both provide movement information (input) and simulate the feeling of touch through haptic force feedback technologies (output);
- **Bodysuits**, (full-body versions of the gloves) to allow motion capture tracking (input) and provide haptic feedback (output);
- **Immersive rooms** (room-size VR solutions) to allow multiple users to experience the same VR content and environment simultaneously. Some of the room settings are based on large-scale tracking (input). Typically, all the walls, the ceiling and the floor can project the digital content (output), which can then be further enhanced by VR glasses or headsets;
    - **Treadmills/motion platforms** to allow full-body movements to navigate the virtual world. Users can walk or run on treadmills and their movements are reproduced by the VR software.

Depending on the application, other types of hardware may be used.

On top of hardware, relevant software and content is required for the development of XR experiences. XR software refers to:

- **XR development platforms** – the framework platforms used for the development of specific XR applications and experiences. Different development platforms may be suitable, dependent on the different types of technologies and hardware involved. The advancement of some of these platforms over the years has increased the user comfort and accessibility of XR experiences;
- **Specific applications** – creation of a virtual world, in the case of VR, or development of an application that brings together the virtual and real world, in the case of AR or MR experiences. This software is developed through framework platforms and includes all the components required to create a specific XR application;
- **XR content** – once an XR application is developed, the software can be enriched with additional content. This content may vary from graphic elements of a VR video game, a 360° video used for the creation of a VR movie and the design of several personalised avatars to the design of physical or non-physical objects in digital prototypes for a demonstration through an AR application.

Gartner Hype Cycle for VR and AR

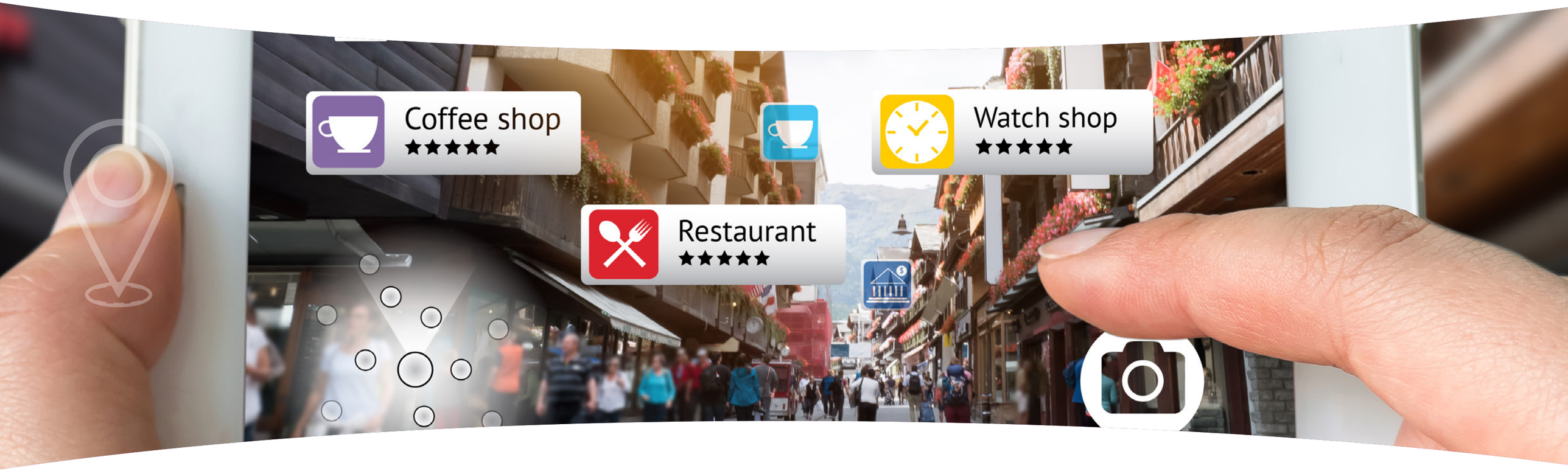


Source: Ecorys, based on Gartner Hype Cycle

The technological maturity of AR and VR is visualised by the Gartner Hype Cycle. The Hype Cycle depicts the general pattern followed by most new and emerging technologies on the market[80], linking the expectation of the public and market to the maturation of the technology over time. The hype surrounding XR technologies initially kept growing to reach the so-called 'peak' of inflated expectations during the period from 2010 to 2012.

In the subsequent period from 2013 to 2014 for VR, and from 2013 to 2018 for AR, difficulties including the physiological time needed to optimise the technology, to develop 'killer applications' and to properly implement it, caused the hype to deflate and the technology to enter the trough of a disillusionment phase. Nowadays, both technologies have passed the slope of enlightenment phase and entered the plateau of productivity, meaning that they are no longer considered emerging, but rather maturing, technologies and thus are more mainstream and widely accepted by the public.

It is important to note that, according to different estimates, the maturity phase has not been reached yet, but it is likely to happen in the next 5 to 10 years. Most estimates tend to agree that XR is a sound technology with clear, proven and profitable applications and the potential to reach higher adoption levels and face an expanding market.



80 Gartner (2012), Hype Cycle, available here.

Annex II – Methodological note

Research methods

Desk research

A major part of the study was conducted through thorough desk research, comprehensive sectoral reports, academic papers and articles from online sources. An exhaustive list of the references used to draft this study is provided below.

Interviews

During the beginning of the desk research we conducted interviews with the aim of getting a clearer understanding on how the XR sector has evolved over the last few years.

Later, we contacted around 200 stakeholders representing the XR ecosystem to gather further insights. We interviewed stakeholders from different European countries, sectors and roles between April and July 2020, via online calls. The main purpose of the interviews was to investigate the following aspects:

- Future trends of XR, both in market and technological terms. Specific attention was devoted to the impact of the COVID-19 pandemic;
- Insights on the three deep dives presented in chapters 4, 5 and 6;
- Characteristics of specific national XR ecosystems;
- Potential policy measures (especially at EU level) to promote the uptake of XR.

Workshops

After the majority of the interviews had been conducted, we organised a series of three online workshops to further discuss the three focus areas selected for the study. The workshops were divided in two sections, with the first one aimed at validating our preliminary results while obtaining additional insights, and the second focused on potential policy measures to strengthen the role of XR in the specific study area.

Here is a summary of the three workshops:

- *Contribution of XR to digitalisation*, 23/06/2020. Nineteen external people participated in the workshop and five members of Ecorys staff were present.
- *Jobs and skills in the XR industry*, 29/06/2020. Twenty external people participated in the workshop and five members of Ecorys staff were present.
- *The impact of XR on sustainability*, 02/07/2020. Twenty-two external people participated in the workshop and five members of Ecorys staff were present.

Events

Our initial plan included visiting a number of XR workshops and events across Europe. However, many were cancelled or postponed due to COVID-19 restrictions. In some cases the organisers proposed an online version of the original event, which we attended in order to gather insights from experts in the XR sector and gain networking opportunities. Here are the events we attended for the purpose of this study:

- *Laval Virtual*, 22-24 April 2020;
- *The future of work* in VR, 21 April 2020;
- *VR/AR Global summit*, 1-2 June 2020.

Ecorys XR industry survey

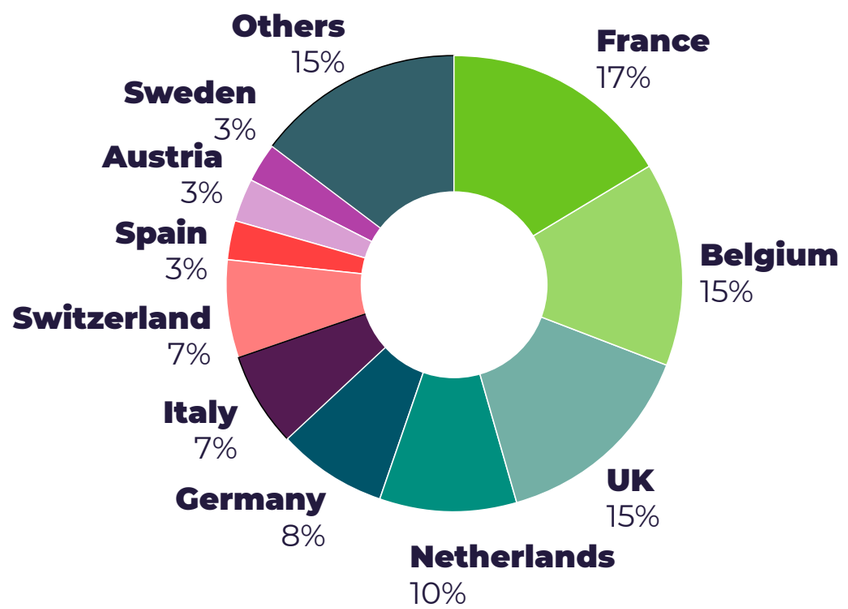
We developed an online survey to gather additional information on stakeholders' perceptions of future XR development and on the market. The survey ran from March to late June 2020. We contacted over 1,500 stakeholders and obtained 285 responses.

The survey targeted two main categories of respondents with dedicated survey sections: XR technology providers and users. The sets of questions were relatively similar and covered the following topics:

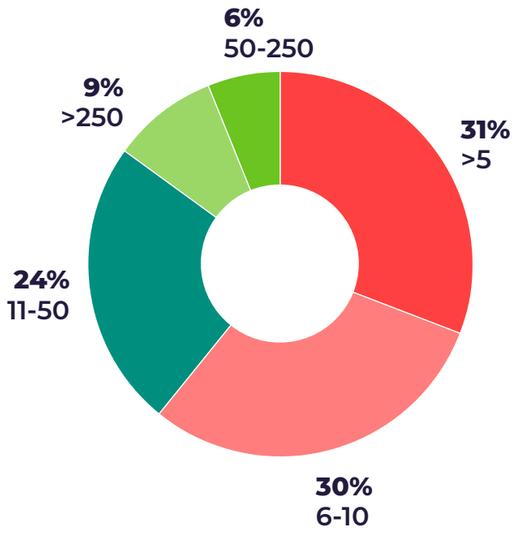
- Organisation and future expectations of the respondent;
- Specific questions on the three deep dives presented in Chapters 4, 5 and 6;
- Strengths and weaknesses of the national XR ecosystem.

Here is an indication of the respondents' characteristics:

Geographical composition of the survey respondents (N=156)



Composition in terms of employees of survey respondents (N=157)



Quantitative assessment of the market
The quantitative market development estimates measuring the industry's growth in the near future (2020-2025) are based upon both quantitative and qualitative information from different sources as well as assumptions. The quantitative and qualitative inputs used for estimating annual XR growth rates, turnover and impacts on the economy and jobs, as well as breakdown per technology, country and component include:

- A comparative assessment of growth rates from market reports listed in the references used to draft this study;
- Results of the survey of XR companies run by Ecorys as a part of this study;
- A critical assessment of future XR market development by relevant academic and industry experts, including observations and expected impacts of COVID-19;
- An analysis of the XR market based on a detailed analysis of more than 2,000 relevant European entities;
- An assessment of growth and the economic impact of three hi-tech industries similar to different XR applications;
- A qualitative assessment of the development of different VR and AR applications based on expert interviews;
- Estimates and growth rates produced in Ecorys' previous VR 2016 report.

However, data gaps at such a granular level remained. It was therefore necessary to make several growth assumptions of the XR market. These included:

- The market for VR and AR professional applications, such as in manufacturing industries, construction or healthcare, is a maturing market with a steadily growing adoption rate;
- The consumer mass market is following an organic adoption curve as access to more affordable and comfortable hardware is emerging and issues regarding the ease of use are addressed. Fulfilment of these conditions cannot be estimated quantitatively;
- Europe is likely to be one of the global leaders in R&D, precise technology manufacturing and creative content development;
- Europe is less likely to drive growth in manufacturing but rather in content production and software development;
- With the growth of the VR and AR market, a higher proportion of the population will be equipped with hardware every year. Once a significant amount of consumers and professional users are equipped with hardware, the growth of the sector will accelerate due to the creation of content and, to some extent, software development;
- Europe will hold or slightly increase its global market share in VR and AR.

Building on these inputs, the forecasts (up until 2025) are based on two scenarios, both with the same starting point, that consider different parameters and potential future developments, such as investments by major technology firms leading to innovation and net effects of the current pandemic on the European XR industry.

In the **baseline scenario**, we foresee a slowdown induced by the pandemic, with the XR industry experiencing steady growth but with lower growth rates than estimated before the pandemic. The industry is still expected to bounce back and approach pre-COVID-19 growth rates by 2024, boosted by moderate growth of the mass market for consumer applications.

In the **optimistic scenario**, following a short-term setback, the XR industry is expected to have bounced back by 2022 and even slightly surpass pre-COVID-19 growth rates, boosted by growing applications such as remote collaboration. Optimal conditions exist for the growth of VR/AR that will stimulate the purchase of headsets by a wider number of consumers, induced by further price drops and advancements in (semi-) immersive experiences (e.g. better-designed human-computer interactions and user interfaces, more user-friendly and comfortable hardware, software optimisation and better performance), breakthrough consumer applications and new content.

Data on job advertisements
Data on the use of VR, AR and XR skills in the labour market were provided by Emsi using their 'job posting analytics' and 'profile analytics' sources, both for the UK market. Job posting analytics are recruitment advertisements which are captured from the internet and then subject to deduplication and classification processes on a daily basis: in a typical month, 800,000 new unique job advertisements are captured in the UK. Profile analytics are professional profiles for individual workers, gathered from opt-in recruitment portals and similar data sources. The database now includes around 14 million individual worker profiles in the UK.

All job postings and professional profiles within the databases are classified using the Emsi skills library which covers around 30,000 unique skill and knowledge attributes. These are then tagged against individual postings and profiles using a text-based classifier. Within the skills library are VR, AR and XR skills which were used individually and then in an inclusive set to run a series of queries on job advertisements and people, looking at the top company names, top job titles and top skills sought by employers or advertised by employees.

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