



Zero-distance XR Applications and Services

Final report

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Abbreviations

XR	Extended reality
EU	European Union
US	United States
AR	Augmented reality
VR	Virtual reality
MR	Mixed reality
AI	Artificial intelligence
TED	Tenders Electronic Daily
UAE	United Arab Emirates
H2020	Horizon 2020
HE	Horizon Europe
VC	Venture capital
SMEs	Small and medium enterprises
HEAC	Horizon Europe Associated Countries
UK	United Kingdom
BIM	Building Information Modelling
NFT	Non-fungible token
B2B	Business-to-business
B2C	Business-to-consumer
B2G	Business-to-government
IT	Information technology
MTS	Motion tracking systems
EEI	Energy intensive industries
HMD	Head-mounted display
CTA	Computer tomography angiography
MRA	Magnetic resonance Angiography
IGS	Image-guided surgery
PTSD	Post-traumatic stress disorder
LED	Light-emitting diode
CPU	Central processing unit
GPU	Graphics processing unit
UI	User interface
UX	User experience
SDK	Software development kit
ERP	Enterprise resource planning
CRM	Customer relationship management
EIF	European Interoperability Framework
HTML	HyperText Markup Language
ROI	Return on investment
R&D	Research and development
R&I	Research and innovation
IP	Intellectual property
EIT	European Institute of Innovation and Technology
KICs	Knowledge and Innovation Communities
ICT	Information and communications technologies
OLED	Organic light-emitting diode
OLEDoS	OLED on silicone
LCD	Liquid crystal display
CT	Computed tomography
eMBB	Enhanced mobile broadband
mMTC	Massive machine type communications
URLLC	Ultra-reliable low-latency communications
WAXR	Wide area extended reality
LAXR	Local area extended reality
HID	Human interface device
SaaS	Software as a service
SoC	System-on-a-chip

CLD	Contact lens display
EOG	Electrooculography
VW	Virtual world
VBS	Virtual battle space
GaaS	Gaming as a service
EIB	European Investment Bank
DG CNECT	Directorate-General for Communications Networks, Content and Technology
DG RTD	Directorate-General for Research and Innovation
OS	Operating system
IaaS	Infrastructure as a service
PaaS	Platform as a service
EU MS	Member State of the European Union
IoT	Internet of Things

1. Introduction

The general objective of the study is to assist the European Commission in designing lines of strategy and preparing actions to contribute to the strengthening of the extended reality (XR) industry and to incentivise industrial digitalisation through the uptake of XR technologies, in a competitive, secure, and ethical environment. More specifically, the objectives of the study are as follows:

- Present a panorama of the EU-wide XR industry and market highlighting opportunities, challenges, gaps, and risks, as well as existing synergies within the ecosystem.
- Provide a clear overview of the XR technologies main use cases, adoption level across the EU industries and sectors, and impact on businesses, processes, marketing, and investment strategies.
- Analyse the extent of the barriers to the adoption of these technologies and possible mitigating measures.
- Analyse global competition aspects, in the context of the dominant US and Asian competition, in order to better assess the EU position, acknowledge the actual risks, and be able to make correct strategic projections for the future of the XR industry.

The study will also help the Commission to orient the work of a possible expert/stakeholder group, and liaise effectively with other related expert bodies at EU- and national-level to ensure comprehensive, multi-disciplinary analytics of the impact on XR technologies in the European economy and society.

1.1. Scope

The study mainly covers the Extended Reality (XR) technologies. While some contexts refer to XR in general, others focus on Augmented Reality (AR) and Virtual Reality (VR). The thematic scope is broader than XR, touching upon related technologies, such as digital twins, 5G, AI, and blockchain. The concepts of virtual worlds, such as the metaverses are also of interest to this study. The definitions of the key concepts of the study are presented in the box below.

Understanding of the key concepts

- Zero-distance refers to the distance between the user and the service. Zero-distance business models exploit the potential of XR technologies, benefiting companies and clients by streamlining processes and shortening the distance between them.
- Extended reality (XR) is the umbrella term used for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), as well as future realities immersive technologies might create. However, XR covers many more technology domains including sensors, data processing, data rendering, and complex hardware and software solutions. VR, AR, and MR are located at different places of the reality-virtuality continuum. This continuum starts from reality, through various augmentations of the reality perceived through our traditional sensory experience to fully virtual reality.
- Virtual worlds are persistent, immersive environments, based on technologies including 3D and XR. These immersive environments make it possible to blend physical and digital worlds in real time, for a variety of purposes, such as designing, making simulations, collaborating, learning, socialising, carrying out transactions, or providing entertainment.¹ In this context, XR could increase the sense of realness making the experience in virtual worlds more similar to real-world experience.

¹ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition, 2023 July 11.

- Metaverse refers to the interoperable network of virtual worlds among which the user can move freely and also have the ability to create and modify the environment.² Metaverse embodies six core elements: immersion, virtual identity, digital assets, real experience, virtual-real interconnection, and complete social system.³

The landscape analysis (Chapter 2) specifically focuses on the following 14 industrial ecosystems⁴: aerospace and defence; agri-food; construction; cultural and creative industries; digital; electronics; energy-intensive industries; energy-renewables; health; mobility – transport – automotive; proximity, social economy, and civil security; retail; textile and fashion; and tourism. The remaining tasks are horizontal and do not have a sectoral focus.

The study covers all EU27 Member States, and the following countries associated with Horizon Europe:⁵

- Countries that already have the association agreements: Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, Georgia, Iceland, Israel, Kosovo, Moldova, Montenegro, North Macedonia, Norway, Serbia, Tunisia, Turkey, and Ukraine.
- Countries with transitional arrangements set out in the General Annexes to the Horizon Europe Work Programme 2021-2022: Morocco and the United Kingdom.

1.2. Methodology

The overall methodological approach to carrying out the study rested on the following data collection methods (see Annex 1 for more details):

1. **Exploratory desk research** helped to review and build upon the existing knowledge base, in order to further develop operational questions and improve the design of study methods. Exploratory desk research also helped to develop the list of stakeholders that were engaged during the interviews, Delphi survey, and workshops.
2. **Desk research** allowed for the collection of background information on the XR industry in Europe across different ecosystems, to prepare the directory of the XR industry associations, and for the inventory of public initiatives and funding opportunities. In addition, desk research laid the foundations for the Delphi survey through the analysis of emerging technologies relevant to XR and allowed to map virtual worlds. The results of the desk research were complemented by interviews, the Delphi survey, and workshops. The list of sources analysed is provided in Annex 2.
3. **Analysis of public procurement and funding instruments** allowed to collect information on the types of XR projects funded and procured through Tenders Electronic Daily (TED), along with providing potential examples of good practices.
4. **Interviews** deepened the knowledge accumulated through desk research and filled in any remaining information gaps. A total of 49 interviews were

² European Commission (2023) Staff working document accompanying the document: An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition. Fabio Moiola "The Metaverse: Don't Confuse It With Virtual Reality" <https://www.forbes.com/sites/forbestechcouncil/2022/08/11/the-metaverse-dont-confuse-it-with-virtual-reality/?sh=3aa792ec2257>

³ Deloitte China "Metaverse report— Future is here. Global XR industry insight" 2022. <https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/technology-media-telecommunications/deloitte-cn-tmt-metaverse-report-en-220321.pdf>

⁴ European Commission website, European industrial strategy, available [here](#).

⁵ Horizon Europe Programme Guide Version 2.3 (15 September 2022).

implemented involving stakeholders from 15 EU Member States and six non-EU countries.

5. **Events attendance** helped to learn about the latest discussions among the industry and other stakeholders. This enabled the study findings to be complemented with the most recent information and insights, which may not be available in the literature yet, and also to engage with different stakeholders. In total, 12 virtual and physical events were attended.
6. **Case studies** of eight selected public initiatives in third countries compared public initiatives and assessed their potential impact on the XR industry at a global-level, and, in particular, for the EU strategic autonomy. Initiatives from the following countries were analysed: the United Kingdom, South Korea, US, UAE, Australia, Argentina, South Africa, and Brazil. The case studies focused on initiatives from various continents and were designed to source insight from outside of EU countries, with the aim to determine whether such initiatives could serve as good examples for addressing challenges that the XR ecosystem is facing in the EU.
7. **Delphi survey** is a method that seeks to aggregate fragmented individual knowledge of renowned experts into collective knowledge. This method can provide useful insights from selected knowledgeable experts when there is a lack of reliable data about the future. In this study, the Delphi survey helped to assess the role XR technologies will play in the EU industry by the end of the current decade and identify the lines of research and emerging paradigms with the greatest potential to break through current technology limitations and accelerate the wider uptake of XR. The Delphi survey was conducted in two rounds with the same group of experts. During the first round XR experts were asked to predict how the XR market can change by 2030, evaluate the likelihood of opportunities and challenges, and rate emerging technologies. During the second round of the Delphi survey, the experts received the results from the previous round to allow them to learn from one another and build consensus among themselves. There were 109 responses to the first round of the Delphi survey and 23 responses to the second round. Since some respondents have dropped out of the survey before fully completing the entire questionnaire, the number of responses per various Delphi survey question reported throughout the Study differs. Unlike for other standard surveys, the 23 responses received provide ground for robust findings, as these responses contain expert insight on XR and emerging technologies. The collective knowledge and experience of 23 XR experts compensate for the small sample size.
8. **Two online workshops.** One workshop was held on June 15, 2023, and was dedicated to validating the preliminary findings of the study and discussing the alternatives and suggestions for policy recommendations. The summary of workshop discussions is presented in Annex 7. The second workshop was held on September 19, 2023, and will be dedicated to presenting and discussing the final study results.

1.3. Structure of the report

The report consists of four main chapters presenting an XR landscape analysis, XR and virtual world-related public initiatives, emerging technologies and their potential impact on XR and virtual worlds development, and an overview of virtual worlds available in the EU. These main chapters are followed by conclusions and recommendations. The report is complemented with the following annexes:

- Annex 1: Detailed methodological approach

- Annex 2: List of sources for desk research
- Annex 3: List of interview respondents
- Annex 4: Interview questionnaire
- Annex 5: Delphi survey questionnaire
- Annex 6: Case studies
- Annex 7: Workshop report
- Annex 8: Exemplary financing cases of EU companies
- Annex 9: Suggested areas for further research
- Annex 10: Presentation event report

2. Landscape analysis

The landscape analysis presents the market and technological status quo in relation to XR technologies. The analysis is carried out for the XR market as a whole, as well as for the 14 industrial ecosystems as defined by the European Commission.⁶ In particular, this chapter:

- Performs a market-wide financial analysis around XR technologies (Section 2.1), looking at various indicators regarding private funding raised by XR companies, and EU-level funding raised by Horizon 2020 (H2020), Horizon Europe (HE) framework programmes, and other public funding and procurement opportunities;
- Assesses the relative relevance of XR technologies (Section 2.2), describing the main applications in use in each of the 14 ecosystems, as well as the most disruptive expected developments for the future;
- Identifies the main needs for broader deployment of XR in terms of hardware, software, and infrastructure (Section 2.3), conducting a comparative analysis between ecosystems and presenting examples of needs that are specific to particular ecosystems;
- Identifies and categorises key barriers to the adoption of XR at a large scale (Section 2.4), using the same approach as the point above;
- Analyses XR-related opportunities for the EU industrial competitiveness (Section 2.5), conducting a market-wide analysis and categorising industrial ecosystems according to innovation types developed by the project team based on different innovation taxonomies⁷.

2.1. XR financing analysis

In a fast-evolving and growing industry, such as XR, improving access to the right private and public funding opportunities for companies is crucial to speed up the maturity and wide adoption of these technologies across the EU.⁸ The EU has already offered significant funding for XR solutions from both public and private sources over the past years, addressing new opportunities and technological challenges in various ecosystems (see section 2.1.2 below). However, it is important to keep track of funding trends, and continuously improve visibility and access to new funding opportunities, as these have been identified as crucial elements by stakeholders in the industry in previous studies.⁹

By understanding the funding landscape for XR technologies, policymakers can make informed decisions on how to support the development of the sector. Therefore, this chapter overviews trends in private funding raised by XR companies and Horizon 2020/Horizon Europe funding for XR solutions, in order to provide insights into the current state of play of investments for XR technologies in Europe. It then moves on to consider public funding and procurement opportunities to paint a comprehensive picture of available opportunities for the XR industry in each industrial ecosystem.

⁶ European Commission website, European industrial strategy, available [here](#).

⁷ Kylliäinen (2019), “Types of Innovation – The Ultimate Guide with Definitions and Examples”, available [here](#).

Dieffenbacher (2023), “Types of Innovation: How the 4 Innovation Types Can Help your Business”, available [here](#).

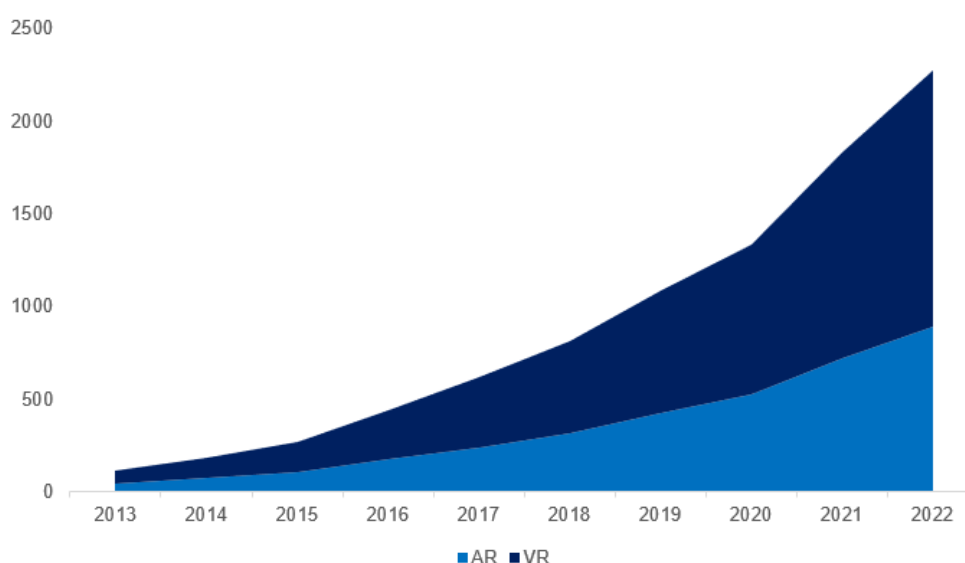
⁸ For a focus on the interlinkages between deep tech industries such as XR and finance, see for instance IE University (2023), *How deep tech is transforming the future of finance*, available [here](#).

⁹ Ecorys (2022), *AR/VR Industrial Coalition*, available [here](#)

2.1.1. Private funding raised by XR companies

According to available data¹⁰, **funding¹¹ raised by XR companies in the EU has been steadily growing over time**, following the recent trends and expectations for sustained growth in the industry. As can be observed in the figure below, XR funding witnessed a **sharp increase starting from 2016**, coinciding with the increase of popularity that surrounded immersive technologies as of that year,¹² and **kept growing the following years, including throughout a period of general economic slowdown due to the pandemic** (+23% yearly cumulative increase in 2020 with respect to the year before). In addition, in more recent years, following a more widespread trend also observed in other economies (e.g., the US), cumulative funding registered a sustained increase, with a yearly growth of +37% and +25% in 2021, and 2022 respectively.

Figure 1. Cumulative funding raised by EU-headquartered XR companies over 2013-2022 (€ million)



Source: Ecorys based on Crunchbase and Dealroom. Data extracted in February 2023.

Looking more in depth at the funding raised each year, **2021 and 2022 witnessed the highest funding raised by XR companies, suggesting an upward trend** (see Figure 2 below), which will need to be confirmed in the upcoming years. Roughly two-thirds of the total funding raised between 2015-2022 was secured by the top 10 recipient companies,¹³. Seed¹⁴ and early-stage¹⁵ venture capital (VC) funding accounts for more than 95% of funding rounds and 60% of the total funding amount.¹⁶ As pointed in recent studies,¹⁷ this concentration of funding in early stages of development hints to **difficulties faced by mid-size companies to access finance to support their potential scaling-up**. This

¹⁰ Authors' calculations based on Crunchbase and Dealroom data.

¹¹ Different types of funding are considered, from both private and public sources, including for instance venture capital, seed, private equity, grants, debt financing. Although considering various types of organisations, sources of data (i.e., Dealroom and Crunchbase) used for the analysis focus on the startups ecosystem.

¹² In fact, immersive technologies experienced a surge in mainstream interest due to the release of one of the most important 'killer applications' for AR, namely Pokémon GO. See for instance Paavilainen, J., Korhonen, H., Kati, A., Stenros, J., Koskinen, E., and Mayra, F. (2017), *The Pokémon GO Experience: A Location-Based Augmented Reality Mobile Game Goes Mainstream*, available [here](#).

¹³ Calculations based on Crunchbase, top 10 companies: Boosteroid, Varjo, Resolution Games, Splink, Neurogaming, Didimo, Oncomfort, LIV, Holo-Light, Holoride.

¹⁴ **Seed**: Among the first rounds of funding; first official equity funding stage, generally while the company is young and working to gain traction; generally, ranges between €8,000 and €1.8 million.

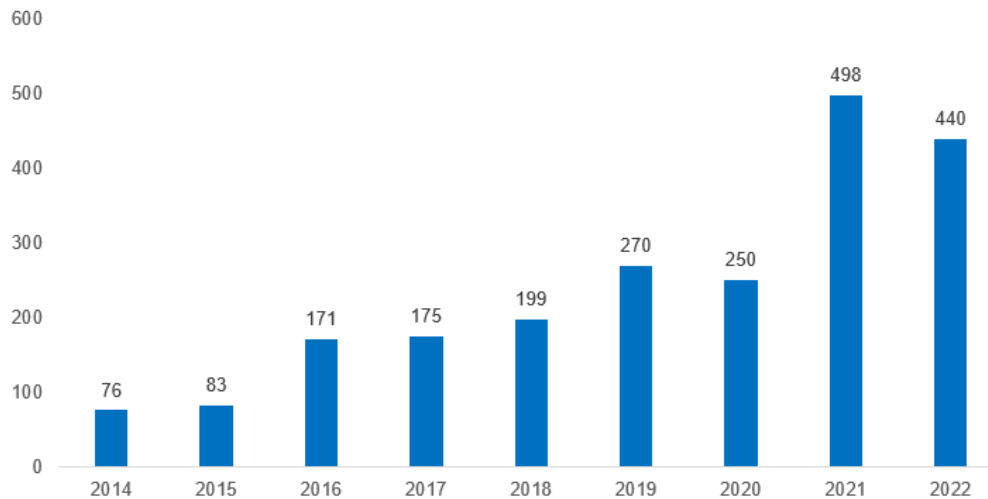
¹⁵ **Early-stage VC**: Series A and B; once a business has developed a track record (e.g., established user base, consistent revenue figures), past the development stage; generally, between €1 and €30,000 million.

¹⁶ Calculations based on Crunchbase

¹⁷ For example, Ecorys (2022), *AR/VR Industrial Coalition*, available [here](#)

constitutes a very pressing challenge by the VR/AR industry, as pointed by multiple stakeholders during the consultations conducted under this study.

Figure 2. Funding raised by EU-headquartered XR companies per year (€ million), 2014-2022



Source: Ecorys based on Crunchbase and Dealroom. Data extracted in February 2023.

Nevertheless, despite the recent observed growth, **EU is still lagging in access to finance (e.g., venture capital), compared with other regions of the world.** In the US, for instance, XR companies have raised over €32 billion¹⁸ during the same period, roughly 14 times higher than the amount raised by XR companies in the EU (see Figure 3 below). This funding gap is not unique to XR technologies, but it reflects a broader issue applicable across other technological sectors and digital technologies.¹⁹ However, the extent of this gap is more pronounced in XR technologies when compared with other sectors such as cloud data services and business information systems companies, for which the gap is narrower.^{20,21} It also should be noted that these data do not capture intercompany investments, which can be substantial in the case of XR market leaders. For instance, Meta has invested roughly \$36bn since 2019 into its Reality Labs, the division of the company that develops VR and AR products.²²

¹⁸ Calculations based on Dealroom

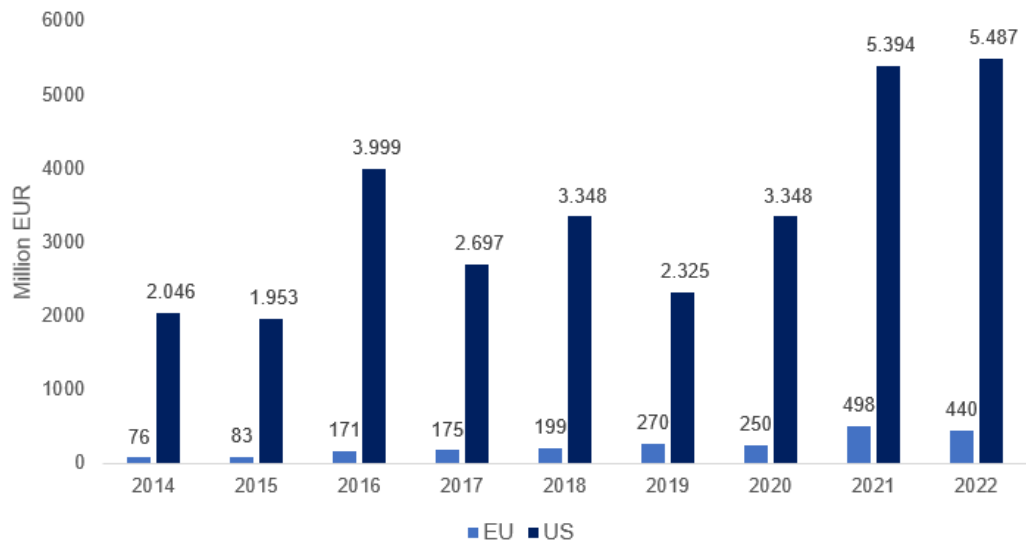
¹⁹ The existence of this gap has been flagged by multiple stakeholders, and is mentioned, for instance, in European Commission (2021), *European scale-up gap: Too few good companies or too few good investors?*, available [here](#).

²⁰ Calculations based on Crunchbase

²¹ Ecorys (2022), *AR/VR Industrial Coalition*, available [here](#)

²² Business insider (2022), available [here](#)

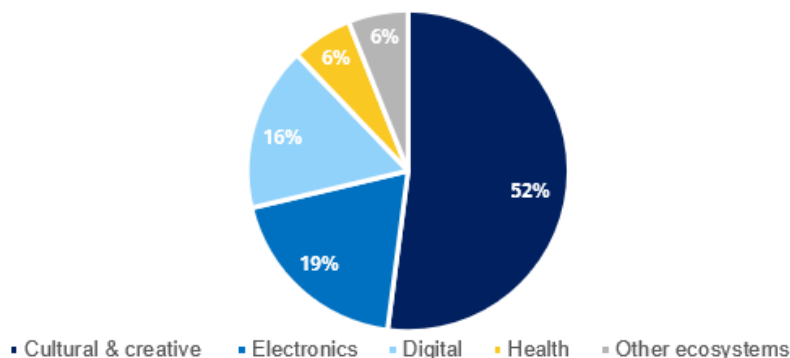
Figure 3. Funding raised by EU vs US-headquartered XR companies per year (€ million), 2014-2022



Source: Ecorys based on Crunchbase and Dealroom. Data extracted in February 2023.

Measuring the funding received per industrial ecosystem proves to be rather complex, as companies often develop applications and operate more horizontally across various ecosystems. However, our results (see Figure 4 below) show that **cultural and creative industries are capturing most of the funding in the EU (52%)**, followed by more horizontal industrial ecosystems, such as electronics and digital industries. Within cultural and creative industries, XR gaming companies attracted most of the investments,²³ indicating gaming's prominence as XR adopter in the consumer market. Even though most of the funding is concentrated in only a few industrial ecosystems, financing success stories have recently emerged across various ecosystems, as shown in the examples in Annex 8²⁴.

Figure 4. Funding raised by EU-headquartered XR companies per industrial ecosystem – 2013-2022 (top 100 recipient companies)



Source: Ecorys based on Crunchbase. Data extracted in February 2023.

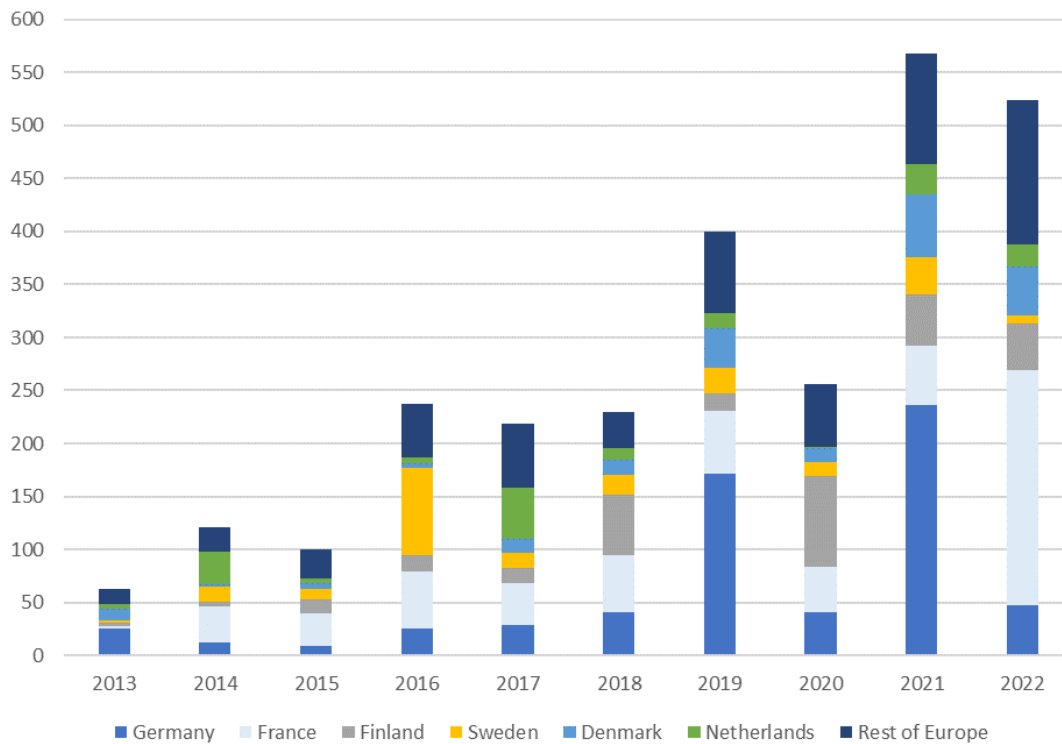
Looking at geographical differences, it can be noted that most of the funding is geographically concentrated in a few countries. Notably, over 2013-2022, almost 80% of total funding was raised by companies located in six Member States in Western and Northern Europe, namely Germany, France, Finland, Sweden, Denmark, and the Netherlands. The share of these countries' cumulative funding has stayed within a relatively constant range over time, fluctuating between 72%-82% of the total funding raised in the EU. While the highest nominal values are registered in France and Germany, funding raised

²³ Ecorys (2022), *The Virtual and Augmented Reality Industrial Coalition – Strategic Paper*, available [here](#).

²⁴ Annex 8 presents some of the top funded companies per ecosystem. All of them, with the exception of the Textile & Fashion and the Tourism ecosystems examples, ranked amongst top 30 recipients of XR investments in the EU.

in Finland and Denmark stand out, particularly when compared to the business population,²⁵ highlighting dynamic XR ecosystems in these countries.

Figure 5. Funding raised by XR companies per country (€ million) – Top 6 EU countries, 2013-2022



Source: Ecorys based on Crunchbase. Data extracted in February 2023.

The European XR ecosystem has been steadily evolving over the past years in terms of research, business, and technological hubs. Looking at the top 100 XR companies in terms of funding raised over 2013-2022 (see Figure 6 below), it can be noted that the main hubs concentrate around a few cities, such as Paris, Stockholm, Helsinki, Prague, Munich, Berlin, and Amsterdam. These cities have been maintaining and expanding their activities, in some cases building strong records in specific application areas or technological focus, and thereby attracting significant funding.²⁶ These cities and their surrounding areas have further strengthened their leading position in terms of companies (including start-ups) focusing on, or engaging in, XR activities and related investments, with multiple additional hubs growing in importance.

²⁵ For a comparison, see Eurostat (2021), *Business demography statistics*, available [here](#).

²⁶ Ecorys (2021), *XR and its potential for Europe*, available [here](#).

Figure 6. XR hubs based on top 100 funding recipients over 2013-2022 in the EU (number of companies)



Note: Paris is the city with the most funding recipients (11).

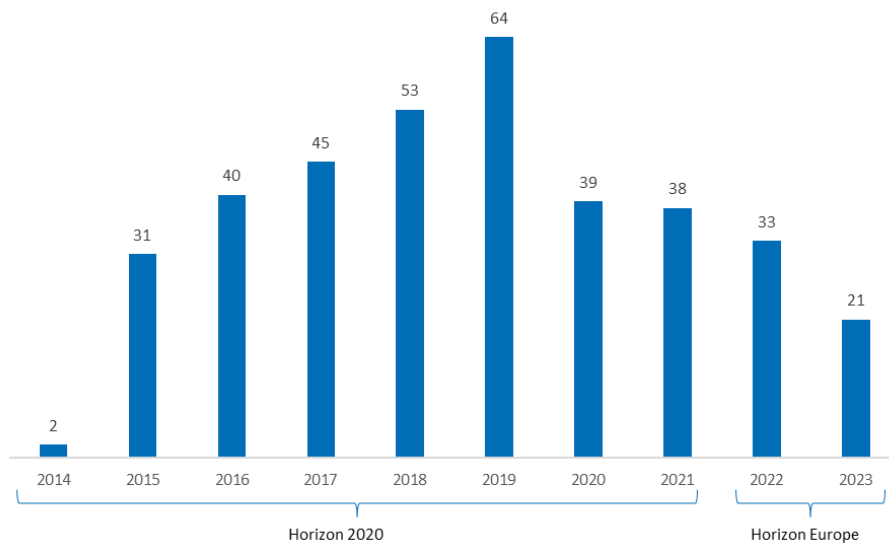
Source: Ecorys based on Crunchbase.

2.1.2. Horizon 2020/ Horizon Europe funding

Various EU-level public funding opportunities exist for companies operating with VR/AR technologies. According to our previous research, **the most accessed European fund by XR companies is Horizon 2020/Horizon Europe.**²⁷ Looking at the Horizon 2020/Horizon Europe databases, the number of projects with an XR component started to gain momentum in 2016 and reached a peak in 2019 (see Figure 7 below). More recently, in 2022 and 2023, 54 projects with an XR component were funded under Horizon Europe, for a total EU contribution of €178.4m. Lower numbers for 2023 compared to 2022 need to be put into perspective considering at least three factors: i) data for 2023 only covers the first two months of the year, not allowing for a definitive trend assessment; ii) a slight decrease in funded projects may arguably have been caused by the transition and adjustment period from Horizon 2020 to the new funding programme, Horizon Europe; iii) the Horizon Europe projects that we have analysed tend to be larger than Horizon 2020 projects (i.e. average EU contribution of €3.3m for Horizon Europe vs €1.9m for Horizon 2020).

²⁷ Ecorys (2022), *AR/VR Industrial Coalition*, available [here](#)

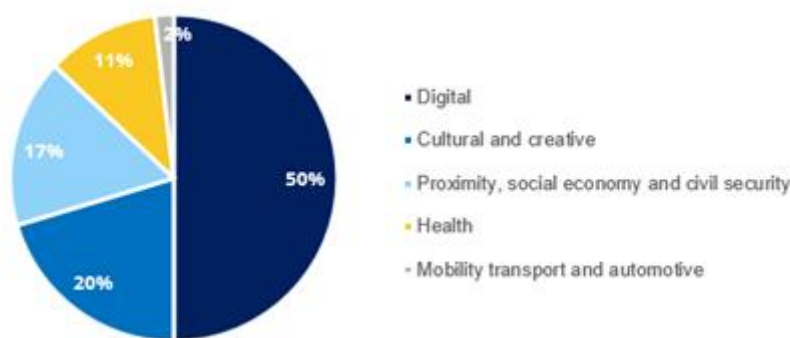
Figure 7. Number of projects with an XR component funded under Horizon 2020 and Horizon Europe, per year, 2014-2023 (data collected in February 2023)



Source: Ecorys based on Horizon 2020 and Horizon Europe database²⁸.

In terms of sectoral coverage, projects with an XR component financed under Horizon Europe span across various industrial ecosystems, with various projects in the digital ecosystem applying horizontally to multiple sectors and being the most prominent (50 % of projects), followed by cultural and creative (20%), proximity, social economy, and civil security (17%), and healthcare (11%).

Figure 8. Breakdown of projects with an XR component financed under Horizon Europe, per industrial ecosystem (% of total) (2022-February 2023)



Source: Ecorys based on Horizon Europe databases.

In the box below, a selection of Horizon Europe projects with an XR component are presented. These projects illustrate innovative (potential) uses of XR technologies to tackle different societal issues and challenges, and/or effectively disseminate messages.

Examples of XR projects financed under Horizon Europe

- **CORTEX2 (101070192)**²⁹ aims at facilitating remote collaboration between workers through next-generation XR technology solutions across a wide range of industries and SMEs. To achieve this, the project is developing a highly innovative and digital XR platform specifically geared to facilitate work and social activities involving physical interaction with the environment and remote objects — from remote assistance or training to working in collaborative spaces. In practice, under CORTEX2 30 projects a total of €4 million will be invested either to develop specific modules of the platform, or to realise new uses cases.

²⁸ Horizon Europe database, available [here](#)

²⁹ Project website available [here](#).

- **SPIRIT (101070672)**³⁰ focuses on the concept of telepresence, i.e. the use of virtual reality technologies especially for remote control of machinery or apparent participation to events. Telepresence represents the next generation of communication applications and will significantly improve immersive experiences in both human-to-human and human-to-machine interactions, by blurring the physical and virtual worlds. Due to their complexity, cost, data compression, and bandwidth requirements, solutions in this sense have not been scaled yet. SPIRIT aims at researching, developing, and demonstrating low-latency and scalable solutions that will ultimately bring real-time immersive telepresence into practice.
- **SHARESPACE (101092889)**³¹ aims at addressing the way new opportunities with XR technologies can lead to the creation of new opportunities for human-centric, safe, rewarding, and inclusive social interaction. SHARESPACE's unobtrusive XR technology will enable intuitive and intelligent interactions between humans and avatars, modelling embodied social behaviour in XR. The functional multimodal-multisensory social broadcasting interface, combined with new knowledge and technology, will have a strong positive effect on future usages, enabling smooth and transparent interaction with AI-powered agents.
- **SUN (101092612)**³² aims at investigating and developing extended reality solutions that integrate the physical and the virtual world in a convincing way, from a human and social perspective. The virtual world developed under the project will be a means to augment the physical world with new opportunities for social and human interaction. The project will pilot developed technologies in three scenarios: rehabilitation, safety, and social interaction at work, and XR for people with mobility and verbal communication diseases.
- **EMIL (101070533)**³³ is co-funded by Horizon Europe and Innovate UK, and will establish both a physical and a virtual infrastructure for a pan-European laboratory that works to accelerate development of virtual, augmented, and mixed reality technologies, content, services, and applications for the media. To achieve this, EMIL will launch and coordinate financial support to third parties through two calls for a total of €5.6 million. Moreover, each of EMIL's four partner institutions will demonstrate latest scientific research knowledge through exemplary Lighthouse Projects in the following areas: Narrative Media Production, Smart Garments, Animation, visual effects, Embodied Interaction, Digital Cultural Heritage, Digital Health, Motion Capture/Analysis, and technological XR development. Entertainment, Health, Media, Exercise, Rehabilitation.
- **MASTER (101093079)**³⁴ enhances robotics training in manufacturing with its open XR platform. It integrates key functionalities, creating safe and flexible robotic environments with advanced interaction mechanisms. The project delivers rich training content and invites third-party contributions through two Open Calls.
- **XR2LEARN (101092851)**³⁵ aims to establish cross-border creation of human-centric XR applications in education. The project will deliver its one-stop shop platform, organised as a Digital Innovation Hub, for all eligible actors involved in the XR-based educational applications supply chain, aimed at enhancing training in manufacturing and distance learning scenarios.
- **XR4ED (01093159)**³⁶ brings together the EdTech and XR communities to establish an European reference platform on learning and training with XR that will provide a central access point to existing solutions and contribute to a leading position for Europe in cutting-edge technologies for education.

Source: Cordis database.

2.1.3. Public funding and procurement opportunities in EU and Horizon Europe associated countries

This subsection presents an overview of public funding and procurement opportunities in EU Member States and Horizon Europe associated countries (HEAC). Within this project we have employed desk research to map main funding opportunities for providers of XR

³⁰ Project website available [here](#).

³¹ Project website available [here](#).

³² Project website available [here](#).

³³ Project website available [here](#).

³⁴ Project website available [here](#).

³⁵ Project website available [here](#).

³⁶ Project website available [here](#).

solutions and technology (both hardware and software) at European-, national-, and regional-levels in EU Member States and Horizon Europe associated countries. Research comprises funding opportunities that were publicly available through desk research that was conducted in November 2022 – April 2023. The analysis of public procurement opportunities overviews public procurement published on Tenders Electronic Daily (TED) and national procurement databases (in the case of Horizon Europe associated countries) between January 2020 and December 2022. For further information on the scope and method of research, please see Annex 1.

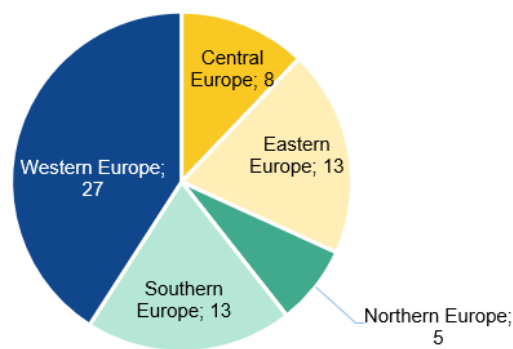
The subsection comprises of the following:

- Overview of funding opportunities, comparing them by their geographic distribution, sector, budget, target group, and geographic scope;
- Overview of public procurement in the EU and HEAC, comparing them by their geographic distribution and other average characteristics, e.g., most common application areas, industrial ecosystems, and spending per ecosystem.

Overview of funding opportunities

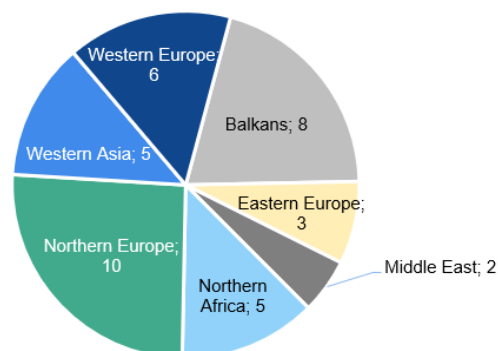
The database compiled for this study comprises 92 funding opportunities, with 58 of them covering EU Member States, and 28 covering HEACs. The most funding opportunities were found in Ireland (EU), followed by the United Kingdom (HEAC). Additionally, the database included six funding opportunities that span multiple countries, with five of them originating from the continent of Europe and one having a global scope. No funding opportunities have been identified in Croatia, Hungary, and Morocco through our research efforts.

Figure 9. Geographical distribution of funding opportunities in EU Member States



Note: Western Europe comprises Belgium, France, Ireland, Luxembourg, the Netherlands; Central Europe comprises Austria, Czechia, Germany, Hungary, Slovakia; Eastern Europe comprises Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania; Southern Europe comprises Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain; Northern Europe comprises Denmark, Finland, Sweden. Research conducted in November 2022 – April 2023.
Source: Visionary Analytics.

Figure 10. Geographical distribution of funding opportunities in HEAC countries



Note: Balkans comprise Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, Serbia; Northern Europe comprises Faroe Islands, Iceland, Norway; Eastern Europe comprises Moldova, Ukraine; Western Europe comprises United Kingdom; Western Asia comprises Armenia, Georgia, Turkey; Middle East comprises Israel; Northern Africa comprises Tunisia, Morocco. Research conducted in November 2022 – April 2023.
Source: Visionary Analytics.

XR funding opportunities in our sample encompass a variety of sectors. For 39 out of 92 opportunities, it was not possible to identify the specific sector based on the available information. The most prominent sectors in the database were research and media, both with 22 funding opportunities. Four funding opportunities were identified as focusing on the

education sector, and another four of the funding opportunities were identified for the tourism sector.

Data on the total budget of funding opportunities was available for only 13 out of the total 92 entries, therefore it is only illustrative of the budgets available through funding opportunities and the following insights should be interpreted with caution. The budgets of the sample of the funding opportunities varies from €50,000 to €180 million. The two funding opportunities with the largest budgets were both based in Ireland. Most of the funding opportunities, for which data was available, fell within the range of one million to €17 million.

Data on the target groups of funding opportunities was available for 72 out of the total 92 entries. The funding opportunities in the sample could be categorised into three target group categories: companies and start-ups, creators, and researchers. Twenty-eight opportunities specifically targeted companies or start-ups providing support in integrating XR into their business, or launching new XR-related enterprises. Thirteen opportunities targeted all types of creators including filmmakers, videographers, app developers, and game developers. Eight funding opportunities were found that specifically targeted researchers aiming to support projects that expand knowledge in XR technologies. In most cases, the target groups belonged to the same sector as the creators of the opportunity (e.g., an art gallery providing funding for creators of immersive artworks). However, companies and start-ups were an exception, as they were mostly targeted by opportunities calling for solutions in the XR field without focusing on a specific industry.

When looking into the geographic area in which the initiative focuses its actions on, out of the 92 funding opportunities in the database, eight opportunities were identified as having an area-specific focus (i.e., target their activities specifically towards the city or municipality area), and six opportunities were identified as having a regional focus within a given country. The majority (78) of funding opportunities were either not identified as having a specific area-focus or operated at a national or international scale.

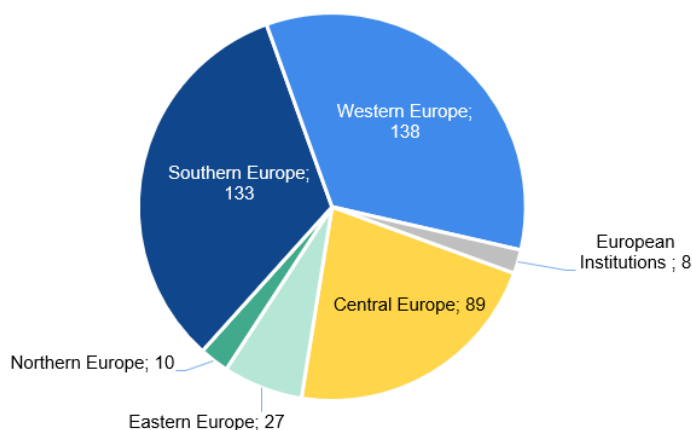
Overview of public procurement opportunities

The total number of entries in the public procurement database for procurement launched between 1 January 2020 and 31 December 2022 (for more details see Annex 1) was 808, with 405 belonging to EU Member States and 403 belonging to Horizon Europe associated countries. Overall, the average number of procurements per country was higher for HEAC (with an average of 21,6 entries per country), compared to EU countries (15 entries per country). However, the number of entries was more evenly distributed among EU countries, with the top three procurement-rich countries accounting for 64% of the share of total procurement opportunities (compared to 91% for HEAC).

Geographic distribution of public procurement

A total of 405 entries in the database were from EU Member States. France was the country with the most procurement opportunities related to XR technologies (109), followed by Greece (77), Germany (74), and Spain (25). As we can see from Figure 11, the highest number of entries came from Western (138) and Southern (133) Europe, while Northern and Eastern European countries launched the fewest public procurements (respectively 10 and 27). There were eight opportunities involving European institutions, which were marked as 'European', regardless of the country, where the contracting authority was based. No relevant procurement opportunities were found in Latvia, Lithuania, Luxembourg, Slovenia, Austria, Cyprus, and Estonia.

Figure 11. Distribution of public procurement opportunities in EU Member States (1 January 2020 – 31 December 2022)

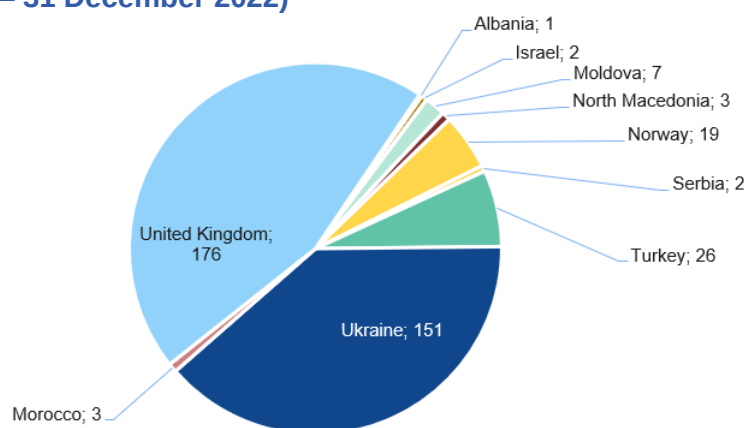


Note: Western Europe comprises Belgium, France, Ireland, Luxembourg, the Netherlands; Central Europe comprises Austria, Czechia, Germany, Hungary, Slovakia; Eastern Europe comprises Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania; Southern Europe comprises Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain; Northern Europe comprises Denmark, Finland, Sweden.

Source: Visionary Analytics.

403 opportunities were identified in HEAC. The country with the highest number of procurements was the United Kingdom, with 176 entries. Ukraine ranked second with 151 entries, and Turkey ranked third with 26 entries. No data emerged for public procurement opportunities from Armenia, the Faroe Islands, Bosnia and Herzegovina, Georgia, Iceland, Kosovo, Montenegro, and Tunisia.

Figure 12. Distribution of public procurement opportunities in HEAC (1 January 2020 – 31 December 2022)



Source: Visionary Analytics.

Average procurement characteristics

To find the average or most-recurring characteristics of procurement in each EU and HEAC country, we considered the most frequently procured XR application areas, the contracting authorities that appeared most frequently, and the ecosystems to which they belong, as well as the average size (value) of procurement.

The application areas of each good or service procured were derived using a bottom-up approach, based on the application areas described in the Terms of Reference of this study. The resulting categories of application are as follows:

- **Training and education:** XR applications for schools, universities and public and private educational settings, to train personnel or to disseminate public awareness/knowledge.
- **Research and development:** Applications employing XR technologies in university or industrial research, and/or for the development of new products or services.
- **Content production:** Applications aimed at showcasing (creative) immersive content including exhibitions, experiences, videos, films, and images.
- **Data visualisation and simulation:** Uses of XR aimed at visualising data or simulating scenarios for non-training purposes.
- **Medical use:** Applications in medical research and practice, encompassing clinical and surgical applications, mental health, social care, and the training of medical staff.
- **Marketing, promotion, and sales:** XR technologies used for marketing purposes or to promote and sell products.
- **Entertainment and cultural or touristic experiences:** Applications aimed at entertaining or educating visitors at cultural events, exhibitions, museums, touristic and heritage sites.
- **Unknown:** The data does not provide clear identification of application areas.

The types of contracting authority follow the categories used in the TED database, while the industrial ecosystems of the procurement entries have been categorised in accordance with the 14 industrial ecosystems, as defined in Chapter 1.

Among the EU countries, *educational institutions* were the most frequently encountered type of **contracting authority** in nine countries, followed by *regional and local administrations* in six countries. In the three countries with the most total entries in the database (France, Greece, and Germany), the majority of procurements fell under the *public administration* sector, involving regional and local authorities, as well as ministries and national, or federal, authorities.

The most frequent **application area** of goods or services procured by each country was *training and education*, which was observed in 15 countries, followed by *medical use* in four countries. However, the application area with the highest overall procurements in the database was *entertainment and cultural and touristic experiences*, with 130 entries. This category was predominately significant in Greece, with 62 out of 77 entries falling under this category, as well as in public procurements launched by European institutions, with three entries out of eight.

Among the three countries that yielded the most entries in the database, Germany primarily procured goods and/or services related to *training and education* (23 entries out of 74, accounting for 31% of the total). On the other hand, both France and Greece saw as the most frequent procurements used for *entertainment and cultural or touristic experiences*. In France, these represented roughly 31% of the total entries (34 out of 109), while in Greece they constituted a much higher percentage of the total (62 of 77 entries, or 80%).

Observing Table 1, it is evident that the *proximity, social economy, and civil security ecosystem* recurred most frequently, appearing as predominant in ten countries and accounting for a total of 96 entries across the whole database. However, the most frequently occurring industrial ecosystem, in terms of the number of entries, was *heritage and tourism* with 116 entries.

Overall **average XR public procurement spending** in the EU ranged from €129,200.00 (Bulgaria) to €35,646,267.37 (the Netherlands). Most procurements fell within the range of €100,000 and €500,000. The countries that, on average, spent the most on XR-related public procurements are the Netherlands (€35,646,267.37), Ireland (€6,533,267.50), and Finland (€4,260,470).

No data for XR-related public procurement was found for Austria, Cyprus, Estonia, Latvia, Lithuania, Luxembourg, and Slovenia. Consequently, these countries have been omitted from the below table.

Table 1. Characteristics of typical EU procurements (1 January 2020 – 31 December 2022)

Country	Type of most-recurring contracting authority	Most-recurring ecosystem	Average total value of procurements	Range of procurement values (in EUR)	Most procured application area	Number of total entries
Belgium	Regional or local authorities	Proximity, social economy, and civil security	€942,300	€539-3500000	Research and development	9
Bulgaria	Educational institution	Proximity, social economy, and civil security	252,700 BGN (approx. €129,200)	€11,550 - 365,593	Research and development	18
Croatia	Inconclusive	Inconclusive	19,556,000 HRK (approx. €2,595,600)	€4,786,000 - 298,740	Inconclusive	2
Czechia	Educational institutions	Proximity, social economy, and civil security	6,972,000 CZK (approx. €295,500)	€17,217 - 799,050	Training and education	7
Denmark	Educational institutions	Inconclusive	6,357,300 DKK (approx. €853,000)	€520000 - 1,205,338	Content production	3
Finland	Public administration, Research institutes	Proximity, social economy, and civil security	€4,260,500	€221,410 - 12,000,000	Inconclusive	5
France	Regional or local authorities	Heritage and tourism	€3,335,500	€3624 - 90,000,000	Research and development	109
Germany	Regional or local authorities	Proximity, social economy, and civil security	€578,000	€6953 - 7,249,700	Training and education	74
Greece	Ministries or national/federal authorities	Heritage and tourism	€452,200	€10,200 - 3,186,156	Entertainment and cultural or touristic experiences	77
Hungary	Regional/local and national/federal authorities	Health	189,003,600 HUF (approx. €505,500)	€189,237 - 1,046,753	Medical use	7
Ireland	Educational institutions	Health	€6,533,300	€240,000 - 45,000,000	Training and education	12
Italy	Educational institutions	Health	€2,358,500	€38,800 - 17,504,158	Training and education	14
Malta	Ministries or national/federal authorities	Proximity, social economy,	€180,500	€29,652 - 298,820	Training and education	8

Country	Type of most-recurring contracting authority	Most-recurring ecosystem	Average total value of procurements	Range of procurement values (in EUR)	Most procured application area	Number of total entries
Netherlands	Body governed by public law	and civil security Proximity, social economy, and civil security	€35,646,300	€919,950–279,000,000	Training and education	8
Poland	Educational institutions	Aerospace and defence	996,700 PLN (approx. €217,400)	€138,600–357,724	Training and education	6
Portugal	Educational institutions	Proximity, social economy, and civil security	€640,300	€190,253 - 1,836,000	Training and education	7
Romania	Educational institutions	Health	1,261,800 RON (approx. €255,900)	€242,734 - 501,400	Medical use	3
Slovakia	Educational institutions	Proximity, social economy, and civil security	N/A (one entry only, value €161 900)	N/A	Medical use	1
Spain	Regional or local authorities	Proximity, social economy, and civil security	€2,191,000	€157,152 - 10,802,073	Medical use	25
Sweden	Inconclusive	Inconclusive	2,500,000 SEK (approx. €236,200)	€235,150 - 236,196	Inconclusive	2
European institutions	European Institutions	Digital	€1,736,000	€252,100 - 4,900,000	Entertainment and cultural or touristic experiences	8
<i>Total for EU</i>	<i>Regional or local authorities</i>	<i>Heritage and tourism (116)</i>	<i>€2,510,700</i>	<i>€539 - 279,000,000</i>	<i>Entertainment and cultural or touristic experiences</i>	<i>405</i>

Source: Visionary Analytics. The exchange rate used was current as of May 9th, 2023. Averages rounded up to the nearest hundred.

In **HEAC countries**, public procurement related to XR was mostly contracted by *educational institutions*, which was also the most frequently occurring **type of authority** in the most countries (6), with a total of 162 entries. Relatedly, the most frequently identified industrial **ecosystem** was *proximity, social economy, and civil security*, which appeared a total of 146 times and was prominent in five countries. The most procured **application area**, or use case, of procurements was *training and education*, with a total of 154 entries and the highest representation in four countries.

In many cases, the number of entries per country was limited, resulting in less insightful data. The most representative data was derived from the countries that produced the highest number of entries in the database: the United Kingdom (176 total entries), Ukraine (151), and Turkey (26). In all three countries, the most procured application area and the most recurring contracting authority were in line with the majority of the overall data, focusing on *training and education for educational institutions*. For Ukraine and Turkey, the most frequent ecosystem also aligned with this pattern. Conversely, in the UK, most procurements were related to the *health* ecosystem.

The **average spending** per each country varied widely among HEAC countries, reflecting the diverse socio-economic characteristics of the represented countries. Israel had the highest average spending compared to other HEAC countries (€20,466,600), followed by the UK (€14,867,600), and Norway (€707,100). All the other countries presented average procurement values in the range of tens of thousands or simple thousands. Notably, Ukraine and Turkey, the second and third most represented countries, had relatively low average spending values (€4,600 and €16,000, respectively). In the database, 150 public procurement entries were under €10,000, while an additional 223 were over €100,000. This suggests that the most procurements fell at the two extremes of the total average, rather than within the middle range.

The following ecosystems have found no correspondence in the HEAC database (and as such are not included in the corresponding table below): energy renewables, retail, textile, and fashion. Among the HEAC, no data emerged for Armenia, Bosnia and Herzegovina, Faroe Islands, Georgia, Iceland, Kosovo, Montenegro, Tunisia. As a result, these countries have been omitted from the table below.

Table 2. Average procurement characteristics in HEAC (1 January 2020 – 31 December 2022)

Country	Type of most-reoccurring contracting authority	Most-reoccurring ecosystem	Average total value of procurements	Range of procurement values (in EUR)	Most procured application area	Number of total entries
Albania	Intergovernmental authority	Cultural and creative	Inconclusive	-	Content production	1
Israel	Ministry or any other national or federal authority, including their regional or local subdivisions	Inconclusive	€20,466,600	€2,260,640.50 – 18,398,600.00	Inconclusive	2
Moldova	Educational institution	Proximity, social economy, and civil security	1,309,700 MDL (approx. €67,000)	€14,501.01 – 174,501.59	Inconclusive	7
North Macedonia	Educational institution	Proximity, social economy, and civil security	226,300 MKD (approx. €3,700)	€2,749.65 – 4,265.33	Training and education	3
Norway	Educational institution	Proximity, social economy, and civil security	8,174,500 NOK (approx. €707,100)	€34,627.57 – 5,539,783.04	Research and development	19
Serbia	Inconclusive	Inconclusive	3,243,600 RSD (approx. €27,700)	€21,308.58 – 34,021.33	Inconclusive	2
Turkey	Educational institution	Proximity, social economy, and civil security	342,700 TL (approx. €16,000)	€2,962.25 – 48,856.48	Training and education	26
Ukraine	Educational institution	Proximity, social economy, and civil security	184,300 UAH (approx. €4,600)	€41.00 – 2,116.71	Training and education	151
Morocco	Inconclusive	Health	731,900 MAD (approx. €67,000)	€101,742.30 – 13,115.80	Inconclusive	3
United Kingdom	Educational Institution	Health	15,016,200 GBP (approx. €14,867,600)	€925.60 – 1,151,246,934.00	Training and education	176

Country	Type of most-reoccurring contracting authority	Most-reoccurring ecosystem	Average total value of procurements	Range of procurement values (in EUR)	Most procured application area	Number of total entries
Total HEAC	for Educational institution (162)	Proximity, social economy, and civil security (146)	Approx. €4,292,701.30	€41.00 - 1,151,246,934.00	Training and education (154)	403

Source: Visionary Analytics (2023). Exchange rates current as of May 10th, 2023. Averages were rounded up to the nearest hundred.

Comparison of public procurements in the EU and HEAC

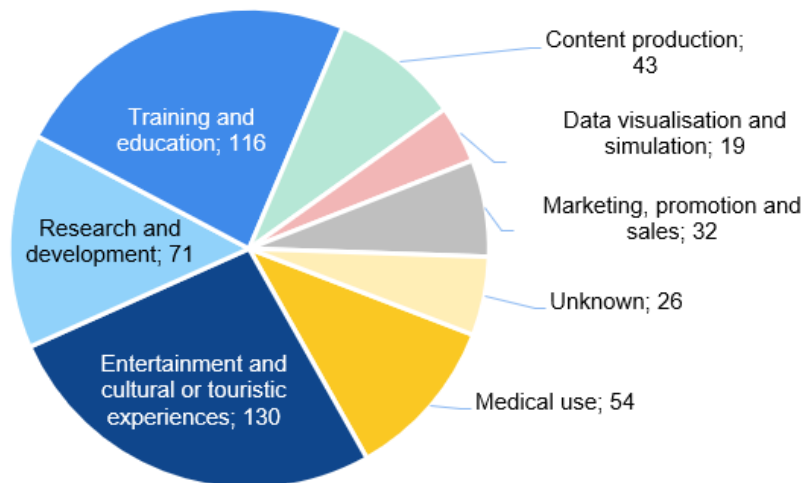
As visible from the below charts, the most sought-after XR **application areas** are similar in the EU and HEAC. In both geographical areas, the top three applications are the same (*training and education*, *research and development*, *entertainment and cultural or touristic experiences*), albeit present in different proportions. The only category that significantly differs in terms of proportion is *marketing, promotion, and sales*, which accounts for 7% of the total in the EU, but only 2% in HEAC countries.

In the EU, the most procured application area was *entertainment and cultural or touristic experiences*, with 130 entries (26%), followed by *training and education* (116 entries, 24%) and *research and development* (71 entries, 14%). In HEAC procurements, the most procured application area was *training and education*, with 154 entries (36%). This was followed by *entertainment and cultural or touristic experiences* (70 entries, 16%), and *research and development* (62 entries, 14%).

If we look at application areas in terms of total spending, we see for both EU and HEAC that there is a stark difference between number of procurements on the one hand, and total spending per application area on the other. This could be due to the fact that governments allocate different amounts of funding for each sector according to their priorities³⁷, or due to the price of XR applications in that area. In the case of HEAC, our sample includes countries that present vastly different socio-economic conditions, as well as differences in the power of the respective national currencies. These divergences could play a role in the discrepancy between distribution of the number of procurements and spending (Figure 14) per application area. This is because one procurement from a ‘wealthy’ country can easily be worth double the price in Euros than one procurement from a less prosperous country, even if they represent the same application area. The procurement data also shows that the vast spending for ‘medical use’ in the spending HEAC chart is by purchases made in GBP by the United Kingdom, for relatively expensive medical equipment (when compared to procurements for goods in other sectors). While this application seems to dwarf others in terms of spending, it should not eclipse visible efforts made by lower-income countries (e.g., Ukraine) to, for instance, introduce VR equipment in schools, such as through purchase of VR goggles (which are cheaper goods than medical equipment). Thus, the below spending data is only illustrative, and larger volumes of spending in EUR should not be automatically assumed to mean a more ‘active’ or widespread use of a certain XR technology.

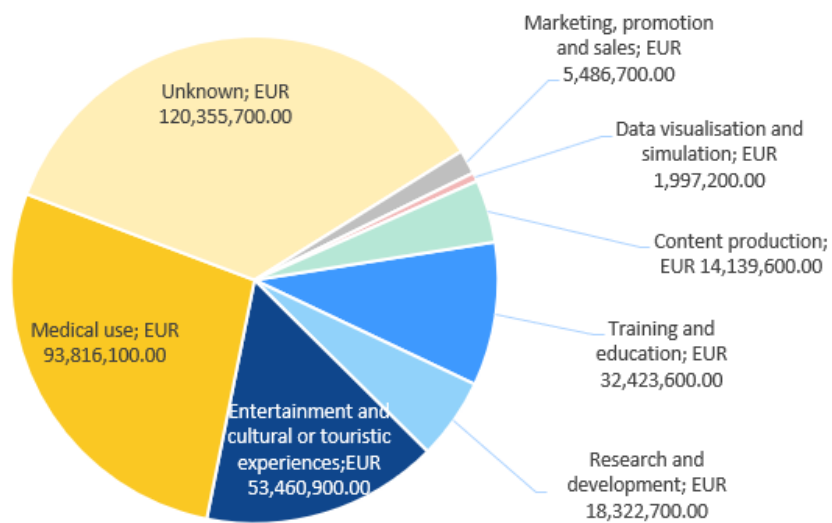
³⁷ See for example the composition per sector of Member States’ recovery plans, which decided to allocate very different amounts of funding for each sector. The full dataset is available at: <https://www.bruegel.org/dataset/european-union-countries-recovery-and-resilience-plans>

Figure 13. Overall distribution of EU procurements' application areas (1 January 2020 – 31 December 2022)



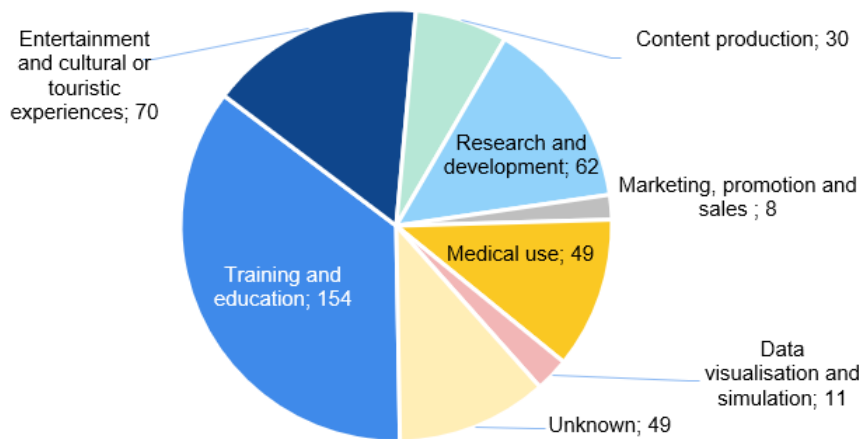
Source: Visionary Analytics.

Figure 14. Total value of EU procurements per application area (1 January 2020- 31 December 2022)



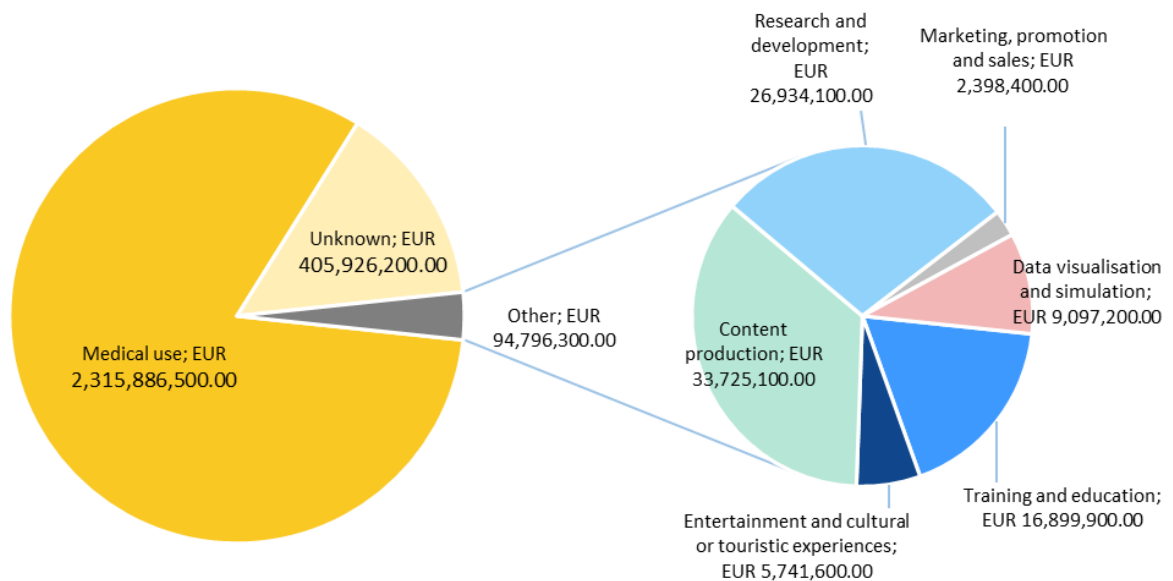
Source: Visionary Analytics. Sums were rounded up to the nearest hundred. Exchange rates current as of May 10th, 2023.

Figure 15. Overall distribution of HEAC procurements' application areas (1 January 2020 – 31 December 2022)



Source: Visionary Analytics.

Figure 16. Total value of HEAC procurements per application area (1 January 2020-31 December 2022)



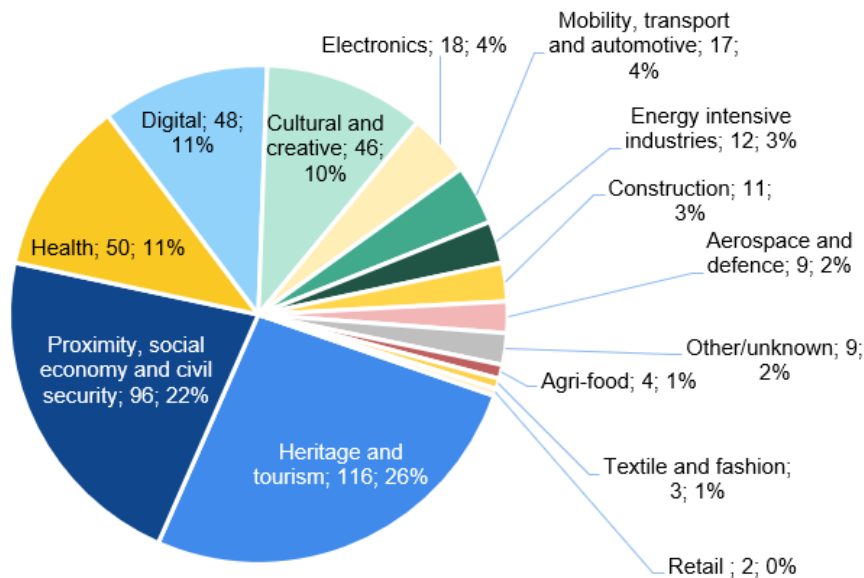
Source: Visionary Analytics. Sums were rounded up to the nearest hundred. Exchange rates current as of May 10th, 2023.

As evident from Figure 17 and Figure 18, we can observe a few differences in terms of distribution of procurements according to their **industrial ecosystem** in EU and HEAC. The variations in ecosystem distribution mirror the findings in the analysis of application areas' distribution. Although the proportions differ, the three most procured ecosystem areas are the same for HEAC and the EU: *heritage and tourism*, *proximity*, *social economy*, and *civil security*, and *health*. These three categories also exhibit the most significant variations in proportions between the EU and HEAC, with all other categories showing differences in proportions no greater than 3%.

In EU countries, the most procured in ecosystem was *heritage and tourism* (26%, 116 entries), followed by *proximity*, *social economy*, and *civil security* (22%, 96 entries), and *health* and *digital* in a tie (both at 11%, with 48 and 50 entries respectively).

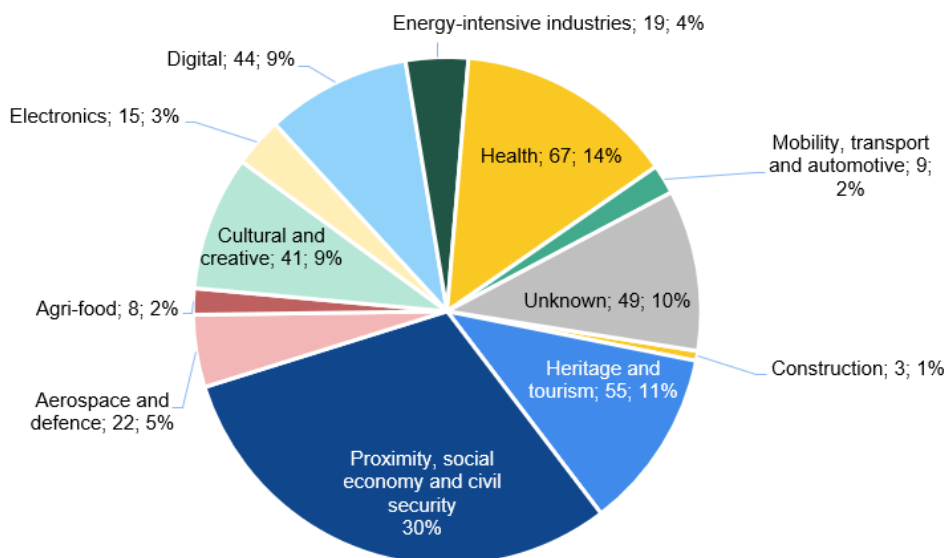
In HEAC, the *proximity, social economy, and civil security ecosystem* was the most procured in, and represented a higher percentage of total number of procurements (146 entries, 30%), compared to the EU. Second, in terms of the number of entries, was the *health ecosystem* (67 entries, 14%), followed by the *heritage and tourism ecosystem* (55 entries, 11%).

Figure 17. Number and percentage of procurements per ecosystem in the EU database (1 January 2020 – 31 December 2022)



Source: Visionary Analytics.

Figure 18. Number of procurements per ecosystem in the HEAC database (1 January 2020 – 31 December 2022)



Source: Visionary Analytics.

Presented below, in Table 3 and Table 4, is the data concerning **spending per ecosystem** in all HEAC and EU countries. Most of the data shows consistencies in EU and HEAC databases, with a few exceptions. For instance, the *proximity, social economy, and civil security ecosystem* had much higher spending in XR-related public procurement in the EU (~€360m) than in HEAC (~€4m), despite the EU number of entries being smaller (96 compared to 146 in HEAC). The amount registered for *health* procurements is also disproportionately high in HEAC (over €2bn). However, this figure is heavily influenced by

two specific procurements from the United Kingdom, which aimed to buy specialised medical equipment, including (but not limited to) immersive and XR equipment.

In the EU, the *proximity, social economy, and civil security* ecosystem recorded the highest spending in XR-related public procurement, totalling €359m. Interestingly, the spending values do not directly correlate with the number of entries: for instance, the *aerospace and defence* ecosystem represents only 2% of entries, but would be sixth in terms of total value. Conversely, the ecosystem with the lowest spending is *textile and fashion*, which is also among the least frequently appearing in the database.

Table 3. Distribution of EU procurement according to ecosystem (1 January 2020 – 31 December 2022)

Industrial ecosystem	Total spending	Number of entries
Heritage and tourism	€ 55,030,842	116
Proximity, social economy and civil security	€ 359,973,703	96
Health	€ 83,704,532	50
Digital	€ 152,802,348	48
Cultural and creative	€ 30,731,423	46
Electronics	€ 3,510,387	18
Mobility, transport and automotive	€ 96,188,010	17
Energy-intensive industries	€ 9,188,746	12
Construction	€ 4,972,523	11
Aerospace and defence	€ 30,363,317	9
Other/unknown	€ 5,358,323	9
Agri-food	€ 961,678	4
Textile and fashion	€ 300,000	3
Retail	€ 600,000	2
Energy renewables	€ 450,000	1

Source: Visionary Analytics. Spending figures rounded up to the nearest whole number. Exchange rates current as of May 9th, 2023.

As previously discussed, Horizon Europe-associated countries have widely different socio-economic characteristics, not to mention variation in purchasing power of national currencies. This led to stark differences in the values of procurements. Therefore, the results presented in the below table will be heavily influenced by procurements from the UK, which had comparatively high values even by EU standards.³⁸ Nevertheless, the UK was Europe's largest extended reality market in 2019,³⁹ thus, these insights from the UK bear considerable informative value for Europe as a region.

In the HEAC database, 49 procurements could not be classified according to ecosystem, accounting for a gap in the data of €405m. The *health* ecosystem accounted for the highest procurement spending in HEAC, with a total value over €2bn. The second-ranking ecosystem was *cultural and creative*, with investments of approximately €33m, while *mobility, transport, and automotive* saw the least investment, amounting to only around €400,000.

³⁸ A study published by DG GROW highlights how UK public procurement of services in 2020 represented 71% of the total value procured at the EU level in awards of more than 100 million Euros. Source: 'Public Procurement Indicators 2020', available at: <https://ec.europa.eu/docsroom/documents/54236> (accessed 19/05/2023).

³⁹ Digital Catapult (2019), 'The immersive economy in the UK 2019'. Available at: https://www.digicatapult.org.uk/wp-content/uploads/2019/11/The_immersive_economy_in_the_UK_2019_Report_November2019.pdf (accessed 19/05/2023).

Table 4. Spending for each industrial ecosystem of HEAC procurements (1 January 2020 – 31 December 2022)

Industrial ecosystem	Total spending	Number of entries
Proximity, social economy and civil security	€24,877,484	146
Health	€2,315,886,542	67
Heritage and tourism	€3,852,719	55
Unknown	€405,926,215	49
Digital	€11,549,371	44
Cultural and creative	€33,674,118	41
Aerospace and defence	€20,453,366	22
Energy-intensive industries	€2,437,168	19
Electronics	€3,065,087	15
Mobility, transport and automotive	€401,010	9
Agri-food	€1,865,236	8
Construction	€2,320,606	3

Source: Visionary Analytics (2023). Exchange rates current as of May 10th, 2023.

2.2. Relevance of XR technologies for the European industry

This section is structured into two parts. One part presents economic position and potential of XR in Europe. The other part presents relevance of XR technologies across different industrial ecosystems.

2.2.1. Relevance and prospects of XR in Europe

A recent study on the economic position and potential of XR in Europe⁴⁰ shows that the market value of the European XR industry is expected to reach between €35 – 65 billion by 2025. It is expected to generate €20 – 40 billion in gross added value, and directly create employment for up to 860,000 people by 2025.⁴¹ Based on other predictions, the European XR market in 2026 will reach a value of around €43 billion as a result of an average annual growth rate of 35%.⁴² This would mean that the XR market would be ten times the size it was in 2018. If a prediction were to be made for the end of the decade, **the European market should reach €88.87 billion by 2030**, up from the registered €7.95 billion in 2021, denoting a projected increase of 1117% during this period.⁴³ Key countries that are expected to promote this growth in the European market include the UK, France, Germany, the Netherlands, Sweden, Spain, and Switzerland.⁴⁴ However, as the market expands, there is also potential in other countries (e.g., Finland, Denmark, Italy, and Greece, as well as in Eastern and Central European countries, including Poland, Estonia, and the Czech Republic⁴⁵).

⁴⁰ The reports overviewed in this section considers Europe geographically, not only as EU, but also including Albania, Bosnia and Herzegovina, Iceland, Norway, Serbia, Switzerland, Turkey, UK, Ukraine.

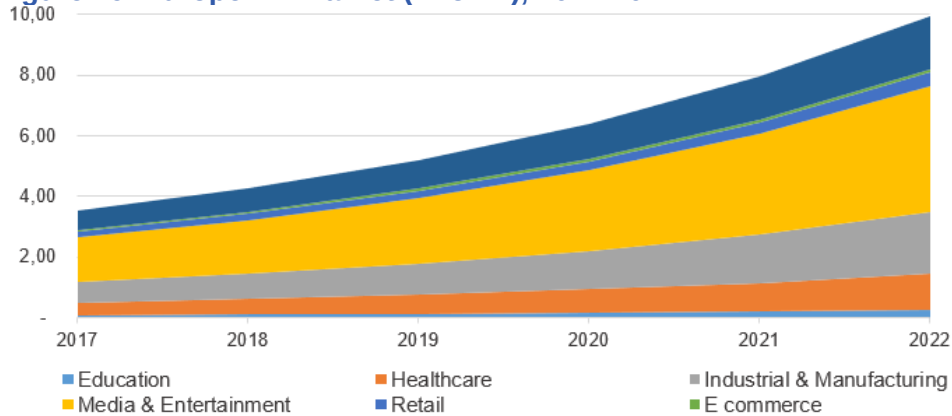
⁴¹ Ecorys, 2021. XR and its potential for Europe. Available at: <https://xreuropepotential.com/assets/pdf/ecorys-xr-2021-report.pdf>

⁴² Centre for the Promotion of Imports from developing countries (CBI), 2021. The European market potential for VR and AR services. Available at: <https://rb.gy/p5gf1>

⁴³ Report Ocean: Europe Extended Reality Market Europe – Industry Dynamics, Market Size and Opportunity Forecast to 2030 (March 2022)

⁴⁴ Ecorys, <https://xreuropepotential.com/assets/pdf/ecorys-xr-2021-report.pdf>

⁴⁵ Ibid.

Figure 19. Europe XR Market (in € Bn), 2017-2022

Source: Report Ocean: Europe Extended Reality Market Europe - Industry Dynamics, Market Size, and Opportunity Forecast to 2030 (March 2022).

The Delphi survey, conducted as part of this study, revealed that the majority (83%, or 65 out of 78) of surveyed experts agreed with the trends presented above, and expected the XR market to continue to grow. During the first round of the Delphi survey, after seeing Figure 19 almost half of experts (45% or 35 out of 75) predicted the growth rate of European XR market by 2030 to be of the same as for the past five years (20–40%), while 38% (30 out of 75) predicted exponential growth (40%+). All the respondents from the second round unanimously (100% or 19 respondents) agreed, or strongly agreed, with the finding on expected market growth. Survey respondents associated this growth with some preconditions, e.g., increasing awareness about XR among general public, the launch of new equipment, and a decrease in its cost. In addition, some respondents shared concern that European XR market growth might only be short-term, and that, after a few years, the market might reach a plateau or decline.

2.2.2. Relevance of XR technologies across different industrial ecosystems

This section provides a comprehensive analysis of the deployment and application of XR technologies in European industries. It examines how extensively XR is being deployed in each ecosystem, as well as its main domains of application, the benefits that the technology adoption provides, and the most promising uses in each industry. By providing a current state-of-the-art overview of the deployment of XR technology, this analysis provides insights into its current use and its potential impact on various industries. Such a relevance analysis is the result of several methodologies, including desk research, interviews with experts and organisations active within each ecosystem, results from the Delphi survey, and event attendance.

In general, it is possible to say that while the types of applications, as well as their technological deployment, varies across ecosystem, the proportion of more advanced and sophisticated solutions has generally increased. This suggests an enhanced understanding of the technology both from an R&I and a final user perspective. Moreover, our analysis indicates that the most important areas of application are i) training and education; ii) data visualisation, simulation and design; and iii) marketing and promotional activities.

- In training and education, XR is widely embraced due to its benefits, mainly enhanced learning outcomes and cost-effectiveness, being relatively well-known.⁴⁶ A Deloitte report⁴⁷ predicts XR to be extremely disruptive in education, even mentioning fully virtual world-native schools as a possible long-term development.

⁴⁶ As demonstrated by the growing body of scientific and academic literature on the subject.

⁴⁷ Deloitte, 2022. A whole new world? Exploring the metaverse and what it could mean for you. April 2022

The COVID-19 lockdown has accelerated the shift from physical to virtual spaces, with positive environmental effects through reduced travel and increased social interaction. Teaching methods are expected to be influenced by XR in terms of both content and modalities, as confirmed by 82% (14 out of 17) of second-round respondents to our Delphi survey.

- In data visualisation, simulation and design, developments of XR regard both the consumer market and the B2B market. In terms of consumer market, the most important sub-sectors include gaming, virtual worlds, the film industry, and entertainment. Innovation and content development is most present in these areas due to the higher level of funding funnelled into them, an element emerged as crucial as part of our Delphi survey. On the business market, XR is used to simplify 3D design processes, to showcase data and/or 3D models to clients to simplify feedback gathering, as well as to streamline and reduce costs associated to some traditional working practices such as product development or prototyping.
- In marketing and promotional activities, XR is leveraged to create immersive and engaging experiences for consumers, including interactive product demonstrations and virtual try-ons. This provides more vivid and memorable brand experiences, as well as improving customer experience by facilitating try-before-you-buy practices and allowing customers to visualise products in their real-world environment. XR-powered promotional campaigns are generally perceived by the public to be innovative and attention-grabbing, enhancing brand visibility and delivering unique storytelling.

Below, we will examine distinct industrial ecosystems, highlighting XR's benefits and transformative potential, and exploring promising applications within each ecosystem. Untapped opportunities are also revealed, emphasising the need for future research, and showcasing XR's vast possibilities for industries.

Aerospace and defence

The level of deployment of XR technologies in the aerospace and defence ecosystem is **medium to high**, in comparison to other industrial ecosystems. The main application domains of XR technologies that are already being deployed in the aerospace and defence ecosystem include training and education, marketing, promotion and sales, and manufacturing and quality control. Among these domains, training and education, along with sales product viewings, are the solutions with the highest level of deployment, while manufacturing and quality control applications have showcased a medium level of adoption.

Both the defence sector and aviation extensively employ **training in virtual or augmented reality environments**.⁴⁸ For instance, defence forces often conduct **emergency military operations simulations** in VR, as it provides a safe and controlled environment for military personnel to experience high-pressure situations, such as hostage rescues and disaster responses, without the risk of physical harm. Immersing trainees in realistic virtual scenarios enables them to develop decision-making, communication, and tactical skills, ensuring heightened readiness for real-world emergencies. **VR combat training**, with full body tracking systems, offers military personnel valuable data from their training exercises. These systems monitor trainees' movements and actions, enabling accurate and personalised performance feedback.⁴⁹ Another common application is **VR vehicle simulation** and equipment familiarisation, which allows military personnel to gain hands-on experience with complex machinery and vehicles without needing physical access.

⁴⁸ Frigo, M. A., Da Silva, E. B., & Barbosa, G. A. S. (2016). Augmented Reality in Aerospace Manufacturing: A Review. *Journal of Industrial and Intelligent Information*. <https://doi.org/10.18178/jiii.4.2.125-130>

⁴⁹ Dymora, P., Kowal, B., Mazurek, M., & Romana, S. (2021). The effects of Virtual Reality technology application in the aircraft pilot training process. *IOP Conference Series*, 1024(1), 012099. <https://doi.org/10.1088/1757-899x/1024/1/012099>

In civil aviation, **VR flying simulators** have become an essential tool for pilot training. By simulating various aircraft types, weather conditions, and emergency scenarios, pilots can develop and maintain their skills without requiring costly and logistically challenging actual flights.⁵⁰ XR has been shown to reduce the cost of schedule disturbances, increase operations and employee satisfaction, and provide remote support when needed.⁵¹ The aviation industry also commonly uses XR to **create immersive sales experiences**, allowing potential customers to explore various design configurations without the need for physical samples.

XR solutions in **manufacturing and maintenance processes** is expected to grow in the coming years. AR applications are increasingly used to enhance operator performance during various tasks, ensuring optimal efficiency, quality, minimal time, effort, and error.⁵² AR solutions enable seamless communication between on-site technicians and off-site experts or managers, streamlining the problem-solving process. In these scenarios, experts can access the camera feed from the technician's headset and provide real-time guidance for executing the necessary repair or inspection.

Agri-food

Overall, the deployment of XR within the agri-food ecosystem is **relatively low**, compared to other industries. However, as technology adoption continues to grow, it is expected to present numerous application domains with the potential to significantly disrupt the agri-food ecosystem. The agri-food ecosystem is primarily utilising XR technology for marketing, promotion, and sales. While other potential applications, such as training, education, and remote collaboration, have been identified, their adoption remains relatively low.

The agricultural and food industries are employing XR technologies as an awareness-raising tool for promoting sustainable practices and informing consumers.⁵³ One way this is achieved is through **interactive packaging**, where consumers can use their devices to access detailed information about the product's origin, production methods, and nutritional content. Another way is through **virtual farm tours**, where consumers can get a first-hand look at agricultural practices, animal welfare, and environmental impacts. Likewise, agri-food businesses are using XR technology in **marketing campaigns** to strengthen their relationship with customers, by showcasing their commitment to sustainability and ethical practices with the overall aim to raise awareness about these values.

Additionally, XR technologies have numerous potential future applications in the agri-food ecosystem.⁵⁴ One example is improving efficiencies in **logistics**, where AR can optimise picking in warehouses by guiding operators to the correct locations quickly, reducing risks of food spoilage or contamination.⁵⁵ Another potential application is enhancing new **food product development**. AR can be used in sensory science to examine aspects, such as consumption, biometrics, food structure and texture, and sensory perception. Product developers can create virtual products and analyse them in real food production settings, allowing them to address issues and deliver low-cost solutions.⁵⁶ Finally, XR technologies are being explored for **crop monitoring and control**.⁵⁷ Researchers and farmers are using

⁵⁰ Ibid.

⁵¹ XR Drives Aerospace Excellence at Boeing. (n.d.). <https://www.sme.org/technologies/articles/2018/july/xr-drives-aerospace-excellence-at-boeing/>

⁵² Safi, M., Chung, J. S., & Pradhan, P. M. S. (2019). Review of augmented reality in aerospace industry. *Aircraft Engineering and Aerospace Technology*, 91(9), 1187–1194. <https://doi.org/10.1108/aeat-09-2018-0241>

⁵³ Jagtap, S., Saxena, P., & Salonitis, K. (2021). Food 4.0: Implementation of the Augmented Reality Systems in the Food Industry. *Procedia CIRP*, 104, 1137–1142. <https://doi.org/10.1016/j.procir.2021.11.191>

⁵⁴ Echegaray, N., Hassoun, A., Jagtap, S., Tetteh-Caesar, M., Sharma, M., Tomasevic, I., Goksen, G., & Lorenzo, J. M. (2022). Meat 4.0: Principles and Applications of Industry 4.0 Technologies in the Meat Industry. *Applied Sciences*, 12(14), 6986. <https://doi.org/10.3390/app12146986>

⁵⁵ Jagtap, S., Saxena, P., & Salonitis, K. (2021). Food 4.0: Implementation of the Augmented Reality Systems in the Food Industry. *Procedia CIRP*, 104, 1137–1142. <https://doi.org/10.1016/j.procir.2021.11.191>

⁵⁶ Crofton, E., Botinestean, C., Fenelon, M., & Gallagher, E. (2019). Potential applications for virtual and augmented reality technologies in sensory science. *Innovative Food Science and Emerging Technologies*, 56, 102178. <https://doi.org/10.1016/j.ifset.2019.102178>

⁵⁷ Salve, S. (2020). Identification of Crop Disease using Augmented Reality-based Mobile App for Indian Farmers: A Prototype. *Human Computer Interaction and Emerging Technologies: Adjunct Proceedings From the INTERACT 2019 Workshops*. <https://doi.org/10.18573/book3.v>

a prototype AR-based mobile application to identify crop diseases, using images of infected crop leaves. In the future, they plan to use actual crop leaves as markers, enabling farmers to quickly identify crop diseases using their smartphones.

Construction

The utilisation of XR solutions in the construction industrial ecosystem is **moderate**, compared to other ecosystems. The most common applications of XR identified are employee training, marketing and sales, design and collaboration tools, and creating virtual tours of properties. These virtual tours enable prospective buyers to experience a property as if they were there in person. The integration of BIM (Building Information Modelling) technologies eases the incorporation of XR in architecture and construction data, as it can be easily uploaded. More sophisticated applications of XR technology, such as collaborative tools for architects, using AR and MR to optimise measurements and prevent risks on construction sites, are also available. XR provides an interactive approach for the public to view infrastructure designs and allows architects to construct 1:1 models of their projects, examine, alter, and test them before they are built.⁵⁸

Employee training is one of the key areas where XR technologies have proven effective in the construction industry. These technologies provide new opportunities for training and practice, leading to improved safety awareness and reduced risk.⁵⁹ **Customer experience** is another area where immersive technologies provide several benefits to the industry. Virtual environments enable designers to communicate and evaluate their ideas, which leads to increased interaction between the design team and customers.⁶⁰ This creates a better understanding of space, allowing architects transmit their design, ultimately improving the overall quality of the project.

Among the potential application domains for the future, within the construction ecosystem, is **advanced planning simulation** and **enhanced collaboration**. XR technology possess the capacity to create sophisticated simulations, allowing professionals to better evaluate construction scenarios, monitor progress, and plan site layouts and equipment placements. Likewise, collaboration tools, enhanced by XR, can facilitate seamless remote cooperation among construction professionals, enabling them to work together on projects regardless of their physical location, leading to improved information sharing and management. Another area of potential is applying XR in areas like **risk identification** and **safety inspection**, whereby professionals can enhance people's experiences and predict how they interact in real-world situations.⁶¹ Virtual environments enable users to assess higher levels of risk and identify more risks than traditional methods, like photos and documents, leading to safer and more efficient construction projects.⁶²

Cultural and creative

The cultural and creative ecosystem is one of the pioneers in the use of XR technologies, as it allows for creative and innovative ways to produce content, through an entirely new media. Therefore, the deployment of XR solutions is **high** in this ecosystem, compared to the others.⁶³

⁵⁸ Website available [here](#)

⁵⁹ Liu, Y., Castronovo, F., Messner, J., & Leicht, R. (2020). Evaluating the Impact of Virtual Reality on Design Review Meetings. *Journal of Computing in Civil Engineering*, 34(1). [https://doi.org/10.1061/\(asce\)cp.1943-5487.0000856](https://doi.org/10.1061/(asce)cp.1943-5487.0000856)

⁶⁰ Rokooei, S., Javan, B., & Nazari, A. (2022). Explore Challenges and Benefits of Virtual Reality in Construction Projects. *Proceedings of the Creative Construction E-Conference 2022*. <https://doi.org/10.3311/ccc2022-037>

⁶¹ Syamimi, A., Gong, Y., & Liew, R. (2020). VR industrial applications—A singapore perspective. *Virtual Reality & Intelligent Hardware*, 2(5), 409–420. <https://doi.org/10.1016/j.vrih.2020.06.001>

⁶² Liu, Y., Castronovo, F., Messner, J., & Leicht, R. (2020b). Evaluating the Impact of Virtual Reality on Design Review Meetings. *Journal of Computing in Civil Engineering*, 34(1). [https://doi.org/10.1061/\(asce\)cp.1943-5487.0000856](https://doi.org/10.1061/(asce)cp.1943-5487.0000856)

⁶³ Ecorys (2022). The Virtual and Augmented Reality Industrial Coalition – Strategic Paper. Available here: <https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1>

One of the most important applications of XR is in **entertainment and cultural activities**. The potential of XR in terms of storytelling is enhanced by the fact users can interact with objects, navigate 3D environment, and witness events from a first-person point of view. **Videogames** using VR and AR are already very successful, and represent around 29% of the whole XR sector,⁶⁴ that is one of the most important applications of XR as a technology, appealing to the mainstream consumer mass and distributed worldwide through digital platforms. Similarly, this storytelling and interaction features are used to create new **immersive experiences** within, or without, the context of traditional moviemaking. XR experiences are entirely different from traditional films, as users can move in a rendered environment, rather than observing through the point of view established by the director.⁶⁵

In the **events industry**, XR can be used to create virtual conferences, trade shows, and other events, enabling attendees to participate in a realistic and interactive environment. Virtual events can be attended by people from all over the world, without the need for travel or accommodation expenses. This makes events more accessible and inclusive, allowing for greater participation and engagement from attendees. Moreover, XR technology provides organisers with detailed analytics and insights into attendee behaviour and preferences. One of the main sustainability benefits of using XR technology for events is the reduction in carbon emissions associated with travel. Physical events often require attendees to travel long distances, which can result in significant carbon emissions from transportation.⁶⁶ **Concerts and live experiences** can also be entirely viewed through a VR headset, or enhanced, thanks to AR applications. This can enrich real life experiences with information or visual effects, or open a new era of entirely digital events.⁶⁷ The same can be said for all those applications dealing with the **sports business**. Images and video, augmented through XR, can display real time statistics and information, provide detailed replays from different angles, or project data related to what is happening on the pitch.⁶⁸

Many promising features are related to XR as a tool for **art creation**. XR defining features, that is its immersivity and interactivity, can be interpreted by artists in unpredictable ways. This allows them to create immersive experiences with an unparalleled storytelling power; to break the barriers of traditional art, by animating pictures and frames through AR technologies; to design and sculpt 3D models and obtain art that is only visible through VR headsets. While many methods, tools, and promotional events (such as virtual showrooms) are nowadays relatively established, they are still not mainstream in many ways. Museums are starting to develop VR or AR **exhibitions**, displaying 3D objects or pieces of art, but much needs to be done – also, in terms of the legal framework necessary to ensure digital representations of artistic piece are not misused.⁶⁹ Additionally, artists now have a new revenue stream in the form of Non Fungible Tokens (**NFTs**), a blockchain enabled technology recognising ownership of digital products, which allow them to sell their art online and to be paid through cryptocurrencies. This market is still very niche, and it is unclear to what extent it will be successful. There is also scepticism surrounding the effectiveness of ledged blockchain systems as alternatives to the traditional currencies market, which might limit its success.⁷⁰ The advent of the metaverse and the increasing

⁶⁴ Ecorys (2022). The Virtual and Augmented Reality Industrial Coalition – Strategic Paper. Available here: <https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1>

⁶⁵ Mitchell, J. (2022). Is VR filmmaking the future of storytelling? Premium Beat. Available here: <https://www.premiumbeat.com/blog/vr-filmmaking-future-of-storytelling/>

⁶⁶ Roos, G., Oláh, J., Ingle, R., Kobayashi, R., Feldt, M. (2020). Online conferences – Towards a new (virtual) reality. Computational and Theoretical Chemistry, 1189. <https://doi.org/10.1016/j.comptc.2020.112975>

⁶⁷ Onderdijk, K.E., Bouckaert, L., Van Dyck, E. et al. Concert experiences in virtual reality environments. *Virtual Reality* 27, 2383–2396 (2023). <https://doi.org/10.1007/s10055-023-00814-y>

⁶⁸ For instance, see Pastel, S., Marlok, J., Bandow, N. et al. Application of eye-tracking systems integrated into immersive virtual reality and possible transfer to the sports sector - A systematic review. *Multimed Tools Appl* 82, 4181–4208 (2023). <https://doi.org/10.1007/s11042-022-13474-y>

⁶⁹ For instance, see Yoo, K. and Gold, N. (2019). Emotion Evoking Art Exhibition in VR. In Proceedings of the 25th ACM Symposium on Virtual Reality Software and Technology (VRST '19). Association for Computing Machinery, New York, NY, USA, Article 108, 1–2. <https://doi.org/10.1145/3359996.3365028>

⁷⁰ For an overview of some criticalities of NFTs as a currency, see Flick, C. (2022). A critical professional ethical analysis of Non-Fungible Tokens (NFTs). *Journal of Responsible Technology*, 12. <https://doi.org/10.1016/j.jrt.2022.100054>

relevance of virtual worlds may boost the volume of these transactions, and establish a new market.⁷¹

Moreover, applications in this sector can overlap with those from other ecosystems, such as tourism, as XR can be used in many cultural contexts, such as museums, schools, libraries, or historical destinations, to present content in an engaging and interactive way – assuring higher retention of information and more empathy when exploring places or cultures.

Digital

The digital ecosystem is quintessential for the widespread adoption of XR technology across other industries and solutions, whether they be B2B (business-to-business), B2C (business-to-consumer), as well as B2G (business-to-government). While there are a few XR technology use cases for IT and telecoms companies, at the moment, the ecosystem is responsible for the research, development and deployment of the software, tools, and platforms that are necessary for any XR application under each of the other industrial ecosystem⁷². Therefore, the level of deployment of XR in this ecosystem is **high**, due to the importance of activities in terms of development of IT solutions for XR. These solutions can be broadly categorised in development tools and platforms, development of virtual worlds, and end user platforms, in addition to data capture, manipulation, and analysis techniques.

Development tools and platforms refer to the software and solutions made available to for developers of XR solutions. The global market is dominated by a few companies accountable for most of the applications' development out there. However, there are many SMEs and start-ups that are creating innovative and specific tools that are made available to developers through development platforms.⁷³ These tools not only cater to application-specific requirements within diverse ecosystems but also serve to streamline and enhance various developer tasks, ranging from customising functionalities for specific applications to standardising and automatising development procedures. The target audience of these platforms is B2B.⁷⁴

Virtual Worlds and end user platforms refer to online-based, interactive environments, where communities can socialise, conduct business or other tasks, and participate in various activities simulating reality. Users interact in these environments by creating text-based, two-dimensional, or three-dimensional, graphical models, which are called avatars. In addition to virtual worlds, there are all sort of user platforms used for accessing XR applications and XR stores – these are sometimes associated with, and developed by, specific hardware providers.⁷⁵ Both virtual worlds and end user platforms' audience are end users, which could either be B2B, B2C, or even C2C, depending on the type of platform and services/experiences offered.⁷⁶

Data capture, manipulation, analysis refer to the set of software, tools, algorithms, and solutions aiming to capture/collect as well as handle the large volumes of data that are collected through XR applications, and produce meaningful insights.

Leveraging on those solutions there is a booming economy of development studios and companies that are producing tailored solutions and content across industries.⁷⁷ Companies focusing on such development are often cross sectoral, offering both very tailored solutions

⁷¹ For instance, see Yilmaz, M., Hacaloglu, T., Clarke, P. (2022). Examining the use of Non-fungible Tokens (NFTs) as a trading mechanism for the Metaverse. European Conference on Software Process Improvement. http://dx.doi.org/10.1007/978-3-031-15559-8_2

⁷² McKinsey (2022), 'What is the metaverse?', available here.

⁷³ Ecorys database of European XR companies (2023 update)

⁷⁴ McKinsey & Company, 2022. Value creation in the metaverse. The real business of the virtual world

⁷⁵ Idem

⁷⁶ Ecorys (2022), AR/VR Industrial Coalition, available here

⁷⁷ Ecorys database of European XR companies (2023 update)

to a specific company/issue, or more off-the-shelf solutions that can be relevant for several sectors or companies.

Electronics

The electronics ecosystem is a key enabler for the widespread adoption of XR technology across other industries. This ecosystem is responsible for driving innovation and conducting research to develop essential components that are necessary for improving XR technology as a whole. This ranges from devices, such as haptics or HMD, to electronic components, that support the overall advancement of the technology. Despite their crucial role, the adoption of XR technology within the ecosystem remains at a **moderate** level. Companies in this ecosystem use XR for training purposes, offering immersive and interactive learning experiences to their workers. Additionally, XR is being deployed in designing electronic components, with a portion of component design taking place in VR.

The electronics ecosystem is advancing the XR technology, by developing a range of hardware components:

- **XR headsets** is a critical component which provides users with the display, sound, and sensors necessary to create an immersive experience. These devices contain high-resolution displays, motion sensors, and audio systems that enable users to interact with virtual environments realistically.
- **Motion tracking systems (MTS)** is another essential component developed by the electronics ecosystem. MTS enables the accurate tracking of a user's movements and position in real-time. These devices rely on a combination of sensors, cameras, and algorithms, to track the user's movements, which is essential for creating immersive XR experiences.
- **Haptic feedback devices** are also necessary for creating realistic and immersive experiences, providing users with the sensation of touch. These devices rely on advanced actuators and sensors, that provide feedback in response to user actions, such as touching a virtual object or interacting with a simulated environment.
- **3D scanners** are devices that are developed in the electronics ecosystem. 3D scanners capture real-world objects in three dimensions, which can then be used to create 3D models for use in XR environments. These devices use a combination of sensors and cameras to capture the shape, texture, and colour of objects, that can then be imported into XR development platforms and engines.

In addition, companies leverage VR and AR solutions for **training purposes**. VR/AR training modules are employed to teach employees about the intricacies of printed circuit board assembly, soldering techniques, and the handling of sensitive electronic components.

Energy-intensive industries

The research findings indicate that XR technology is being used in several domains of the energy intensive industries (EII) ecosystem,⁷⁸ including training and education, quality control, and data simulation. However, the level of XR deployment in the EII is currently **low to medium**, when compared to other ecosystems. Among the various applications of XR in the EII, training and education is the most prevalent, particularly when safety procedures are involved in hazardous scenarios. In addition, XR is emerging as a tool that complements remote maintenance and inspection tasks, which currently involve online person-to-person interaction.

XR training is commonly applied in EII ecosystem to address industrial demands, such as industrial symbiosis and circular economy, where EIIs must increasingly integrate and

⁷⁸ EII is composed by the following sub-industries: cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, pulp and paper, refining, steel, and water.

consolidate their previously separate industrial processes.⁷⁹ XR safety training is also often used, as it offers numerous advantages, especially for companies within the EEI ecosystem that frequently operate in hazardous and challenging environments. XR-based training significantly reduces training costs, as the virtual environment can be simulated without the need for real materials. Research studies indicate that XR-based training is considerably more effective than traditional training methods.⁸⁰ Overall, immersive training benefits are well-known. It enhances the effectiveness of training, while reducing costs, enabling enterprises to ensure that their employees are well-prepared to handle potentially unsafe situations in real-world scenarios.

Remote quality control and maintenance tasks enhanced by XR applications have the potential to revolutionise the way energy-intensive industries operate, significantly reducing downtime and streamlining processes.⁸¹ Through electronic devices, such as a mobile phone, a tablet, a computer, or a head-mounted display (HDM), digital information is superimposed on real images, enriching the information available to maintenance operators. This allows operators to access crucial data about systems, such as their references, operating states, and guidelines for maintenance, or assembly or disassembly of parts. HMDs and stereoscopic glasses have the potential to enhance user experience, offering hands-free usage and a more realistic, immersive point of view for workers. The actual application of XR in this ecosystem involves an expert providing instructions to a technician on-site, ensuring accurate and efficient maintenance or repair. As technology advances, it is anticipated that these operations will become increasingly automated. In conjunction with artificial intelligence, HMDs will have the capability to overlay the necessary information directly onto the technician's field of view.

Energy renewables

Overall, interviews and desk research⁸² implemented as part of this study suggests that the level of deployment of XR technologies across the renewable energies industrial ecosystem is **low to medium**. That is because deployment differs across sectors within the ecosystem. It is low for most sectors, i.e., solar energy, hydropower, bioenergy, geothermal energy, marine energy, smart infrastructure, and energy conversion technologies. Meanwhile, deployment is medium in the wind energy, heat pump, and sustainable energy storage sectors.

XR deployment in the **wind energy** sector is characterised by B2B solutions that facilitate training, maintenance, and product presentation. In the **training** domain, applications pertain to replacing dangerous, impossible, counterproductive, or expensive to run on-site trainings with VR-based ones. In **manufacturing and maintenance**, digital twins of wind turbine rotor blades are being developed for better remote monitoring and AR goggle-assisted workflows are being introduced. Finally, **product presentation** in wind energy refers to virtual viewings of power plants and turbines. The former tends to target the

⁷⁹ Salah, B., Abidi, M. H., Mian, S. H., Krid, M., Alkhalefah, H., & Abdo, A. (2019). Virtual Reality-Based Engineering Education to Enhance Manufacturing Sustainability in Industry 4.0. *Sustainability*, 11(5), 1477. <https://doi.org/10.3390/su11051477>

⁸⁰ Knoke, B., Quandt, M., Freitag, M., & Thoben, K. (2021). Virtual Reality Training Applications in Industry - Towards a User-friendly Application Design. Goto Verlag EBooks, 59–80. https://doi.org/10.30844/wgab_2021_4

⁸¹ Morgado, M., & Miguel, L. F. (2018). Ergonomics in the Industry 4.0: Virtual and Augmented Reality. *Journal of Ergonomics*, 08(05). <https://doi.org/10.4172/2165-7556.1000e181>

⁸² This section is based on analysis of the following websites: <https://kronoterm.com/en/support/kronoterm-ar/>; <https://mastertherm.cz/mobilni-aplikace/>; <https://ramboll.com/digital-solutions/assets/true-digital-twin-sub>; <https://ramboll.com/services-and-sectors/energy/wind-energy/virtual-reality-offshore-wind>; <https://tpsc.com/en/success-stories/augmented-reality-from-tt-psc-supports-the-production-processes-of-vestas-the-largest-wind-turbine-company-in-the-world/>; <https://www.ait.ac.at/en/research-topics/digitalisation-and-hvac-technologies/projects/hvac-positioner>; <https://www.andritz.com/hydro-en/hydronews/hn32/virtual-reality-fairs>; <https://www.atlascopco.com/en-gr/construction-equipment/resources/toolkit/energy-storage-system-augmented-reality>; <https://www.dutchmarineenergy.com/marine-energy/vr-experience>; <https://www.enbw.com/company/press/augmented-reality-for-visualisation-of-wind-power-plant.html>; <https://www.idm-energie.at/en/virtual-idm-heat-pump-is-here/>; <https://www.kanda.dk/siemens-case>; <https://www.reliablade.com/partners>; <https://www.reply.com/en/3d-and-mixed-reality/ar-and-vr-for-photovoltaic-plants>; <https://www.tesvolt.com/en/service/tesworld-app.html>; <https://www.vr-lab.nl/wind-turbine/>; <https://www.youtube.com/watch?v=9Ux9KGDDptg>.

broader public for educational purposes, while the latter tends to target wind power plant operators.

Unlike in wind energy, XR deployment in the **heat pump and energy storage** sectors, is more B2C heavy. The reason for this is that the main application domain is **product presentation**. In particular, a number of heat pump and energy storage solution providers boast AR-based smartphone applications that allow customers to visualise, for example, a heat pump in their home according to their personal preferences. The underlying goal then is to facilitate sales, by allowing customers to make a more informed purchase decision.

An important observation based on the insights from the interviews and desk research is that wind power-related VR and AR applications are heavily concentrated in Northern Europe, especially with Danish companies (Vestas, LM Wind Power, Olsen Wings, Force Technology), or companies operating in Denmark (Siemens Gamesa). Other applications are found in the Netherlands (Windpark Nijmegen-Betuwe), and Germany (EnBW), with only Spain-based Acciona, being located outside of the region. This concentration is not particularly surprising, considering that Northern Europe is the EU region where (offshore) wind energy is the most abundant and prevalent, due to the region's favourable geography and relative wealth. Furthermore, XR users in (wind) energy generation tend to be large corporations with vast financial resources, while SMEs are prevalent among XR users in the heat pump and energy storage segments.

Health

The level of deployment of XR technologies in the health ecosystem is overall **high**, compared to other ecosystems, but varies across Europe, with the highest level of deployment in Germany, the Netherlands, and France.⁸³ In recent years, the adoption of XR technologies in the EU healthcare industry has been increasing gradually, driven by the growing awareness of its benefits and advancements in technology. An analysis of XR revenue by industry shows that healthcare comes in third place with a 12% (€1.19 billion) share of the XR market, following media and entertainment in first place, and industrial and manufacturing in second place.⁸⁴

XR is being used in the healthcare sector in the following areas:

- **Medical training and education.** Medical students and professionals use XR technologies to simulate surgeries, medical procedures, and patient interactions, allowing them to gain hands-on experience. This improves the quality of medical education and training.
- **Preoperative planning** benefits from XR technologies, such as AR, VR, or holograms (MR), that allow surgeons or radiologists to accurately assess a patient's condition in 3D, using conventional 2D scan data, like Computed Tomography Angiography (CTA) or Magnetic Resonance Angiography (MRA) images. Advances in Image-guided Surgery (IGS) include registering images and instruments to the patient, tracking instruments in real-time, and displaying a realistic model of the operative volume. The aim is to improve patient outcomes through less-invasive procedures and shorter hospital stays, leading to increased accuracy and reduced X-ray exposure, ultimately contributing to efficient clinical workflows.
- **Remote collaboration and telemonitoring**, as well as hands-free image capturing via voice commands to maintain sterility during surgery.⁸⁵ This approach is beneficial

⁸³ Interviews with SyncVR, Sint Maartens, EIT Health; European Commission, Directorate-General for Communications Networks, Content and Technology, Boel, C., Dekeyser, K., Depaepe, F., et al., Extended reality : opportunities, success stories and challenges (health, education): final report, Publications Office of the European Union, 2023. Available [here](#).

⁸⁴ Report Ocean, 2022

⁸⁵ Hamacher, A., Kim, S. J., Cho, S. T., Pardeshi, S., Lee, S. H., Eun, S. J., & Whangbo, T. K. (2016). Application of Virtual, Augmented, and Mixed Reality to Urology. *International Neurourology Journal*, 20(3), 172.

in emergency situations where less experienced surgeons can be guided by more experienced colleagues. The ability to analyse the same data simultaneously may also aid preoperative planning.⁸⁶ Moreover, the use of VR/AR technology can provide patients with a visual representation of surgical procedures, allowing them to better understand what will happen, or has happened. This can be more effective than relying on a physician to explain complex medical information.

- **Treatment of mental health** disorders or to alleviate pain, anxiety, and stress reduction in medical procedures. VR therapy has been shown to be effective in treating conditions, such as anxiety, post-traumatic stress disorder (PTSD), nervousness, and phobias. By creating immersive environments that simulate real-life situations, patients can confront and overcome their fears in a controlled and safe environment.
- XR technologies offer **opportunities for surgeons** to enhance their performance during surgical procedures, resulting in reduced errors and improved efficiency.
- **Improving patient outcomes** in physical therapy and rehabilitation. XR technologies can be used to create personalised exercise programs, and provide real-time feedback to patients, allowing them to monitor their progress and adjust their treatment plans accordingly.
- **Improving virtual hospital visits** by creating more immersive and interactive experiences for patients. For example, virtual reality headsets can transport patients to a simulated hospital environment, where they can interact with their surroundings and healthcare providers through avatars. This can help to reduce feelings of isolation and anxiety that patients may experience during hospital stays.

The overall use of XR technologies in healthcare is increasing with sophisticated applications being deployed tackling complex challenges faced by the healthcare industry. The adoption of health XR technologies in the EU is being driven by factors, such as the growing demand for advanced healthcare solutions, increasing investments in XR technology by healthcare providers, and advancements in XR technology.

Mobility – transport – automotive

The mobility – transport – automotive industrial ecosystem is instrumental in both adopting and promoting the widespread use of XR technology. European car manufacturers are at the forefront of XR innovation, securing numerous patents, and proactively incorporating the technology into their processes. The level of XR adoption in the mobility – transport – automotive ecosystem is **high**, compared to other ecosystems. XR solutions are implemented across the entire production and maintenance cycle, spanning from initial design to vehicle repair. Furthermore, XR is employed to simulate diverse scenarios, which serves to improve autonomous driving systems and identify mobility trends.

XR technology is being used in the automotive industry for a variety of training purposes. **Technical skills training** can be conducted in immersive environments that allow learners to practice and develop their skills with virtual vehicles and components. In addition, XR is also aimed at users, for example during **safety training**, as the technology allows for the simulation of dangerous situations and trains drivers to respond safely without the risk of actual harm. **Assembly line training** is also often used, as it can familiarise new employees with procedures and standards, leading to smoother transitions. **Sales and customer service training** can improve sales techniques and customer experiences. The usage of

<https://doi.org/10.5213/INJ.1632714.357>; Khor, W. S., Baker, B., Amin, K., Chan, A., Patel, K., & Wong, J. (2016). Augmented and virtual reality in surgery—the digital surgical environment: applications, limitations and legal pitfalls. *Annals of Translational Medicine*, 4(23). <https://doi.org/10.21037/ATM.2016.12.23>

⁸⁶ Andersen, D., Popescu, V., Cabrera, M. E., Shanghavi, A., Mullis, B., Marley, S., Gomez, G., & Wachs, J. P. (2017). An Augmented Reality-Based Approach for Surgical Telementoring in Austere Environments. *Military Medicine*, 182(S1), 310–315. <https://doi.org/10.7205/MILMED-D-16-00051>

immersive training in the ecosystem presents an improvement of the professional formation processes, as it reduces time and resources, while the training occurs in a controlled and safe environment.^{87,88}

Marketing promotion and sales can lead to increased customer engagement and potentially higher sales.⁸⁹ Companies in this ecosystem are employing XR tools to enhance both online and in-person sales processes. For example, virtual showrooms are becoming increasingly popular, where customers can interact with vehicles, change colours, and experiment with different configurations. Additionally, XR is transforming the physical sales experience for car dealerships by allowing customers to explore available vehicles, features, and customisation options in an interactive environment. XR demonstrations are also being used to showcase the unique features and capabilities of each vehicle, making the sales process more engaging and informative.

During the **design and prototyping** phase, XR enables engineers and designers to create, and interact with, virtual prototypes of vehicles and components. This results in faster design iterations, improved collaboration among teams, and more efficient product development processes.⁹⁰ Moreover, VR is being increasingly used to **simulate realistic and complex environments** for testing autonomous driving systems or mobility models, that aim to improve urban mobility.^{91,92} VR is also used to **simulate the car assembly process** in production lines to estimate the necessary steps and time.

A promising feature that is emerging in the automotive and transport industrial landscape is the AR solutions focused on **complex assembly and maintenance procedures**. By overlaying information objects onto real-world scenes, AR interfaces can effectively guide technicians through intricate tasks, providing them with essential information and visual cues in real time.

Proximity, social economy, and civil security

The adoption rate of XR technologies in the proximity, social economy, and civil security industrial ecosystem is increasing, but it varies across different sectors and use cases. In the **proximity sector**, the adoption rate of XR technologies is **relatively high**, with many companies and organisations using XR to create immersive experiences for customers. Despite variations in adoption rates across different industries within the **social economy sector**, the overall level of adoption of XR technologies could be described as **moderate**, however, it has been increasing recently with many organisations using XR to create educational and training experiences that promote social and environmental well-being. In the **civil security sector**, the adoption rate of XR technologies is also increasing, with many security agencies using XR to train personnel and simulate emergency scenarios. However, the adoption rate in this sector is **still relatively low**, compared to other industries, as the technology is still relatively new and there are concerns about the cost and complexity of implementing XR solutions.

While analysing the proximity ecosystem, it must be noted that the ecosystem covers services and businesses that prioritise local and short value chains. As a result, the use cases and application of XR technology, in some cases, are the same as in other industrial ecosystems. Hence, these applications are described in the descriptions of dedicated

⁸⁷ Pusda, F. R., Valencia, F., Andaluz, V. H., & Zambrano, V. D. (2019). Training Assistant for Automotive Engineering Through Augmented Reality. Lecture Notes in Computer Science. https://doi.org/10.1007/978-3-030-25999-0_13

⁸⁸ Syahidi, A. A., Subandi, S., & Mohamed, A. (2020). AUTOC-AR: A Car Design and Specification as a Work Safety Guide Based on Augmented Reality Technology. Jurnal Pendidikan Teknologi Dan Kejuruan, 26(1), 18–25. <https://doi.org/10.21831/jptk.v26i1.27907>

⁸⁹ Tarafdar, P., A. Leung, W.T. Yue, and I. Bose (2019). impact of Immersive Interface Design on Consumer Perceptions during Online Product Presentation", in Fortieth International Conference on Information Systems (ICIS), Munich.

⁹⁰ Čujan, Z., Fedorko, G., & Mikušová, N. (2020). Application of virtual and augmented reality in automotive. Open Engineering, 10(1), 113–119. <https://doi.org/10.1515/eng-2020-0022>

⁹¹ Djavadian, S., Farooq, B., Vásquez, R. E., & Yip, G. (2019). Virtual immersive reality based analysis of behavioural responses in connected and autonomous vehicle environment. Elsevier EBooks, 543–559. <https://doi.org/10.1016/b978-0-12-817340-4.00027-9>

⁹² Vásquez, R. E. (2021). Novel Methods In Training Autonomous Vehicles For Urban Roads. Toronto Metropolitan University Thesis. <https://doi.org/10.32920/16838284.v1>

ecosystems (namely applications in retail, real estate, fashion, advertising and marketing, and events). In the **proximity ecosystem**, the most promising applications of XR technologies are in areas, such as retail, real estate, telecommunication, events, advertising and marketing, and hospitality. XR technology is rapidly being adopted in the **telecommunications industry**. Telecommunications companies are also leveraging XR technology to provide better customer experiences. For example, virtual store tours and product demonstrations can be created using XR technology, allowing customers to interact with products in a virtual environment before making a purchase. XR technology can also be used to enhance customer service, by providing virtual assistants that can guide customers through the buying process. In **hospitality** sector XR can enhance the guest experience and provide new opportunities for engagement, e.g. by providing virtual tours of hotels, resorts, and other hospitality locations. Guests can use XR to explore a property before booking, also to access information about nearby attractions, restaurants, and other points of interest, which can help them make more informed decisions about where to stay.

In the **social economy**, XR technologies have the potential to revolutionise education, sustainability, and entertainment. For example, in **education**, XR can be used to create virtual classrooms, enabling students to interact with teachers and classmates in a more engaging and immersive way. To explain the importance of **sustainability** and attract investment and awareness, a narrative is essential. Tech companies may assist to communicate these messages in a variety of formats, including projection mapping, interactive digital displays, and virtual reality experiences. AR and XR can give unique views on topics, by displaying previously unavailable locations and scenarios.⁹³ In **entertainment**, XR can be used to create immersive and interactive television, gaming, and film experiences. AR and TV create a new hybrid medium that opens up new possibilities for storytelling and audience engagement. Broadcasters are trying to increase engagement through interactive data services, leading to TV evolving from just audio-visual to interactive. ARTV has the potential to personalise the TV-watching experience by adding virtual elements to the real-life viewing experience.⁹⁴ Presenters can improve their performance in XR setups, by seeing the virtual world projected on LED walls, making the experience more immersive for them and the viewers.

In the **civil security ecosystem**, XR technologies have the potential to play a major role in areas, such as military training, emergency response, and criminal investigations. For example, in **military and police training**, XR can be used to create realistic simulations of combat scenarios, allowing soldiers to practice in a controlled and safe environment. Emerging technologies promise a superior military force capable of addressing both conventional and asymmetrical threats. In **emergency response**, XR can be used to create virtual simulations of emergency scenarios, enabling emergency responders to practice and prepare for real-world situations. VR technology for **fire safety training** creates an immersive experience that presents employees with realistic simulations of various fire scenarios, allowing them to train and enhance their emergency response skills within a secure and supervised environment. VR-based **evacuation training** presents personnel with interactive scenarios that simulate real-life situations, allowing them to learn the appropriate procedures for evacuating a building, and how to respond effectively during emergencies. The training provides an immersive experience that helps personnel to understand and practice the correct actions to take in such scenarios.⁹⁵ In **criminal investigations**, XR can be used to recreate crime scenes, and enable investigators to analyse and understand the events that took place.

Retail

In the European retail sector, the adoption of XR technologies has been **moderate**, compared to other industries. The research reveals that immersive solutions are primarily

⁹³ Website available [here](#)

⁹⁴ Vatavu, R.-D., Saeghe, P., Chambel, T., Vinayagamoorthy, V., and Ursu, M.F. (2020). Conceptualizing Augmented Reality Television for the Living Room. ACM International Conference on Interactive Media Experiences. <https://doi.org/10.1145/3391614.339366>

⁹⁵ Website available [here](#)

used for customer-based solutions in marketing, promotion, and sales, transforming both online and in-store customer interactions. Additionally, we have identified XR applications in the domains of training and education for employees, as well as design and prototyping applications, though to a lesser extent.

Online XR solutions provide users with unique product experiences and information without visiting physical stores. These solutions enable customers to **virtually try on** products, such as clothing accessories, eyewear, and cosmetics, in any chosen surrounding, supporting the purchase decision.⁹⁶ European retailers are also using **virtual showrooms** and **immersive advertising experiences**, including Metaverse activities, to engage customers with their brands.

In-store XR solutions, on the other hand, focus on attracting customers and sparking curiosity, making the shopping experience more appealing.⁹⁷ The combination of mobile devices and online retailing scenarios with AR technology is a popular choice, providing seamless experiences.

The effects of using XR in retail include positive attitudes, increased decision comfort, higher willingness to pay, and enhanced shopping experiences. The presence of, and interaction with, XR can improve customer experience in stores or online apps. Furthermore, AR can enhance store attractiveness, satisfaction, brand engagement, willingness to share personal information, and intentions to return to the AR app, or engage in word-of-mouth marketing.⁹⁸

The reviewed literature suggests that XR technology, which allows users to try out and interact with virtual products, can increase informativeness and value perceptions. Additionally, affordances that enable point-of-view sharing between customers can further enhance this informativeness. As the European retail ecosystem continues to evolve, XR technologies are set to play a crucial role in shaping the future of customer interactions, marketing strategies, and overall shopping experiences.

Textile and fashion

XR tools have multiple applications throughout the textile and fashion ecosystem, yet, when compared to other industries, their implementation remains at a **moderate** level. In the same way as in the retail ecosystem, XR is focused on customer experience and sales. In the context of e-commerce, XR, and 3D environments are generally used for presenting online new collections. Virtual try-ons are being developed to enable customers to make informed buying decisions through virtual representations of clothing, which is considered the future of the industry. While XR can be used for design purposes, it is not widely used as design programs on 2D surfaces are still effective.

Fashion brands are employing XR tools to create **virtual products** or virtual showrooms, allowing customers to visualise products in real-time and in a variety of contexts, thus reducing the information gap between the digital and physical environments. Similarly, AR-powered mobile applications enable users to **virtually "try on"** apparel and accessories, enhancing purchasing decisions and providing a seamless shopping experience. Digitally reproduced products in e-commerce platforms offer a realistic representation of fashion items, enabling consumers to carry out more informed online purchasing decisions. Textile firms are also leveraging XR technologies with promotional campaigns, to increase consumer interest in products. For example, the rise of the virtual worlds has driven the adoption of fully digital products, with non-fungible tokens (NFTs) being utilised to

⁹⁶ Hilken, T., De Ruyter, K., De Ruyter, K., Mahr, D., & Chylinski, M. (2020). Seeing eye to eye: social augmented reality and shared decision making in the marketplace. *Journal of the Academy of Marketing Science*, 48(2), 143–164. <https://doi.org/10.1007/s11747-019-00688-0>

⁹⁷ Adam, M. & Pecorelli, M. (2018). Recommendations in Augmented Reality Applications - the Effect of Customer Reviews and Seller Recommendations on Purchase Intention and Product Selection. Publications of Darmstadt Technical University, Institute for Business Studies (BWL) 105776, Darmstadt Technical University, Department of Business Administration, Economics and Law, Institute for Business Studies (BWL).

⁹⁸ Riar, M., Korbil, J. J., Xi, N., Zarnekow, R., & Hamari, J. (2021). The Use of Augmented Reality in Retail: A Review of Literature. *Annual Hawaii International Conference on System Sciences*. <https://doi.org/10.24251/hicss.2021.078>

authenticate and transact exclusive virtual items. In the **fashion industry**, virtual reality allows clients to personalise clothing and virtual stores. AR enables furniture manufacturers to offer clients to experience new furniture in their own homes before purchasing.

The fashion industry is gradually adopting more XR-based business solutions.⁹⁹ For example, an application that presents promising potential is the use of AR in virtual try-on together with IoT mirror technology to offer customers a more accurate **"try-before-you-buy"** experience, with personalised outfit suggestions based on individual characteristics, such as skin or hair colour, body size, and shape.¹⁰⁰ This real-time augmentation of clothes can lead to a more immersive and engaging shopping experience for consumers. Clients will be able to try on fashion items and make decisions based on information displayed on mirrors. In addition, the incorporation of XR technology into the design process is enabling designers to experiment with various design elements, such as colour, embroidery, texture, and carving, more efficiently and cost-effectively.¹⁰¹

Tourism

XR applications are widespread across the entire tourism value chain. When compared to other industries, the extent of XR technology integration in the tourism ecosystem is **medium to high**. The primary applications domains where XR is employed include marketing and advertising, as well as entertainment and cultural experiences. Although it is employed to a lesser degree in training, its usage is still noteworthy. Within the context of marketing and advertising, XR technology plays an important role in promoting destinations, hotels, and hospitality facilities. For instance, it enables potential clients to preview rooms, or embark on virtual tours of hospitality venues, increasing the likelihood of securing bookings. Furthermore, XR enhances cultural experiences by offering immersive virtual tours of popular attractions and providing real-time information on tourism destinations through AR applications.

VR is commonly adopted in the museum industry to enhance **cultural experiences by offering immersive virtual tours**. By utilising VR headsets, controllers, and sensors, visitors can delve into rich, interactive environments that recreate historical contexts, showcase artistic masterpieces, and foster a deeper understanding of the subject matter.¹⁰² Museums across Europe have successfully implemented VR experiences that allow visitors to explore artists' studios and gain insights into their creative processes. These immersive experiences not only make the museum collections more engaging, but also help overcome the challenges of reduced attention spans, as visitors become more absorbed in the narratives being presented.¹⁰³ Additionally, VR technology can facilitate the **virtual reconstruction of archaeological sites** or buildings, increasing heritage awareness and providing visitors with a unique perspective on the past.

AR has the potential to emerge as a ground-breaking technology in the tourism industry, offering a wealth of benefits to travellers by enhancing their touristic experiences. By seamlessly integrating digital information with the physical world, AR enables visitors to **access relevant information in real time and with little effort**, and improve their understanding of tourist destinations, while simultaneously providing engaging entertainment.¹⁰⁴ For example, applications are being developed to provide personal

⁹⁹ Huang, X. (2022). How Is Fashion Going: Structured Literature Review for Circular Economy in Fashion and Textile Industry. *Frontiers in Business, Economics and Management*, 3(3), 114–118. <https://doi.org/10.54097/fbem.v3i3.358>

¹⁰⁰ Vaseem Akram, S., & Kumar Malik, P. (2022). Implementation of Digitalised Technologies for Fashion Industry 4.0: Opportunities and Challenges. *Hindawi Scientific Programming*, 2022(Article ID 7523246). <https://www.hindawi.com/journals/sp/2022/7523246/>

¹⁰¹ Starkey, S., Alotaibi, S. M. A., Striebel, H., Tejeda, J., Francisco, K. E., & Rudolph, N. C. (2021). Fashion inspiration and technology: virtual reality in an experimental apparel design classroom. *International Journal of Fashion Design, Technology and Education*, 14(1), 12–20. <https://doi.org/10.1080/17543266.2020.1844807>

¹⁰² Trunfio, M., Della Lucia, M., Campana, S., & Magnelli, A. (2021). Innovating the cultural heritage museum service model through virtual reality and augmented reality: the effects on the overall visitor experience and satisfaction. *Journal of Heritage Tourism*, 17(1), 1–19. <https://doi.org/10.1080/1743873x.2020.1850742>

¹⁰³ Baran, Z., & Baran, H. (2022). The Future of Digital Tourism Alternatives in Virtual Reality. *IGI Global EBooks*, 58–84. <https://doi.org/10.4018/978-1-7998-8528-3.ch004>

¹⁰⁴ Cibilić, I., Poslončec-Petrić, V., & Tominić, K. (2021). Implementing Augmented reality in Tourism. *Proceedings of the ICA*, 4, 1–5. <https://doi.org/10.5194/ica-proc-4-21-2021>

electronic guides and tour assistants for cultural site visitors, offering a multimode user interface that delivers cultural data, restoration details, and archaeological insights for tourists. Using HMD or electronic devices, visitors can visualise historical figures and scenes within their physical surroundings, fostering a more immersive and interactive experience. The proliferation of AR technology in the tourism sector not only enhances the visitor experience, but also presents new opportunities for tourism organisations and destinations. By offering novel and interactive ways to explore unknown regions, AR applications create a competitive advantage for enterprises, helping them attract and retain tourists. The applications allow tourists to have an entertaining educational experience, while exploring the site in unique ways.

2.3. Needs for broader deployment of XR

In this section we present the main needs, identified over the course of the research done under this study, that should be addressed to facilitate and foster the broader deployment of XR technologies in Europe. In particular, we focus on the optimal conditions for the uptake of XR, and on the technological advancements required – in terms of hardware, software, or infrastructure. These must be addressed to favour the ecosystem as a whole, and boost the success of studios and companies creating content, developing, and researching XR.

We will present the main needs that have been found in literature and mentioned by interviewed or surveyed stakeholders throughout analysis of 14 industrial ecosystems. In addition, throughout the text, we will provide some examples of needs specific to clusters or single industrial ecosystems. These specific examples emerged from interviews with stakeholders across ecosystems. Importantly, these do not necessarily represent ecosystem-wide trends; rather, they exemplify how some of the needs we identified can translate into practice.

2.3.1. Hardware needs

The needs collected and presented in the table below regard hardware advancements that, according to research and industry players, are critical for the further development of XR technologies and their successful uptake over the next years. The table presents an overview of the most important hardware needs identified, together with a short description, and indicates which needs have been found to be critical for current deployment and/or future uptake of XR in each ecosystem.

Table 5. Hardware-related needs

Need	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Advanced tracking	Technology used to track user's movements and eye gaze to create more seamless experiences and reduce motion sickness	x			x								x	x	x
High-performance CPUs and GPUs	Required to ensure smoother and more responsive XR experiences as these become more complex	x		x	x		x	x	x	x	x	x	x	x	
High-resolution displays	Required to provide users with more immersive and realistic experiences	x			x					x	x	x	x	x	x
Sensors	Sensors such as cameras, accelerometers, gyroscopes and depth sensors provide input to the processor and are at the basis of data elaboration	x		x			x	x		x	x	x			
Haptic hardware	Haptic devices provide users with tactile feedback. They can be improved in terms of feedback, tracking, range of sensations, and design	x							x				x	x	
Ergonomic headsets	Headsets are the main interface for VR and MR experiences, but are still often uncomfortable to wear for extended periods of time			x	x		x	x		x	x				
Wireless headsets	Wireless headsets remove limitations to user's movements and range, and allow to access XR experiences regardless of the location		x	x	x			x	x	x	x		x		

ZERO-DISTANCE XR APPLICATIONS AND SERVICES

Need	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Battery life	Improved batteries allow for longer usage time without the need to recharge the device		x	x	x					x					
Audio hardware	High-quality audio is a key component to create immersive experiences				x							x			x

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

Our analysis underlined how certain hardware needs are considered critical in a wide number of ecosystems, making these advancements particularly important for the development of XR as a whole. Particularly, the **need for high-performance CPUs and GPUs** has been marked as critical in 11 ecosystems out of 14. This is because, regardless of the specificities of each application used in different ecosystems, higher processing power (and its availability at a non-prohibitive price) is necessary to make the most out of existing XR solutions, and to allow developers more ambition in creating new ones.

Computing power and tracking needs in the civil security ecosystem

AR technology is still in its early stages of development, and many technical challenges need to be addressed before it can be effectively used in the civil security sector.¹⁰⁵ For example, AR requires powerful computing resources and high-speed internet connectivity to function properly, which may not be available in all environments. Another reason is that the civil security sector has specific requirements that may not be easily addressed by existing AR technology. For example, one critical aspect of civil security applications is the ability to track objects and people in real time, particularly in complex environments where there may be many moving parts, such as crowds or high-speed transportation systems. While AR systems have shown promise in enhancing situational awareness, they may face challenges when it comes to real time tracking in complex environments because AR systems often rely on sensors, cameras, and other input devices to capture data and create a digital overlay on the real-world environment. In complex environments with many moving objects, it can be difficult to accurately capture and process this data in real-time, leading to potential inaccuracies and delays in tracking objects and people. Additionally, civil security applications may require higher levels of accuracy and precision in tracking compared to other AR applications, which can pose technical challenges for AR developers.

Source: stakeholder consultations with sector experts.

Similar considerations can be made about the need for more **advanced high-resolution displays and sensors** (marked as critical in eight and seven ecosystems respectively), which would increase the overall quality of XR solutions and lead the technology into the next generation of visual fidelity, image realism, and parameters tracked.

Another cross-sectoral need regards **wireless headsets**. These are now becoming the new standard in the consumer market, thanks to the highly successful and relatively cheap Oculus Quest 2. However, they are still not the norm when it comes to higher-end devices, which still need to be plugged into powerful computers to process information, or to dedicated external input devices to track specific parameters. The fact that this need is relatively widespread across ecosystems (marked as critical in eight out of 14 ecosystems) partly explains why the need for **better battery life** is still considered relatively less important (marked as critical in four ecosystems out of 14): since wireless headsets are still not the norm, the need to improve their battery life is reduced.

Having more **ergonomic headsets** is a general improvement that would benefit users and professionals across all ecosystems. However, our research suggests that such an advancement would be critical for further uptake in six ecosystems – less than half of the total. The key variable in this sense is likely to be the average length in terms of usage time of VR/MR headsets. This is the case of ecosystems offering experiences to end customers or patients (cultural and creative ecosystem, retail, health), or for those where professionals would need to wear headsets for extended periods (health, mobility-transport-automobile, energy-intensive, and construction).

A less cross-sectoral need is **advanced tracking**. This is crucial in ecosystems that employ more advanced solutions related to subjects' movements, such as in the aerospace and defence, or the cultural and creative ecosystems, or that require further advancements in the precision of this technology to make potentially disruptive applications feasible in the future – such as for the retail and the textile ecosystems, see box below.

¹⁰⁵ Source: Visionary Analytics, 2023. Information provided by company representatives during interviews, <https://onebonsai.com/>

Advanced tracking for next-generation virtual try-ons in the textile ecosystem

Virtual try-on refers to the use of XR technologies to simulate the experience of trying on clothes, accessories or garments. Currently, these are mostly used through smartphone-power AR applications that display a digital representation of the object to be purchased and superimpose it to the user's features through built-in smartphone cameras.¹⁰⁶ However, this process is not particularly precise with the current state of technology, and it is not able to show a garment in real time, on a real person in motion. Advanced tracking technologies, combined with other developments, such as more powerful CPUs and GPUs, AI integration, and image-recognition technologies, would significantly contribute to next-generation virtual try-ons. These would allow garments to be adjusted not only to users' movements, but also to their specific body features and size, making virtual try-ons a solution able to properly inform a purchase decision on a wider set of clothes and accessories. Moreover, customers could design their own products or tailor pre-rendered options, making production more specific to each order received, and avoiding overproduction and product waste.

Source: stakeholder consultations with sector experts.

Other needs seem to be more niche to specific ecosystems. Haptic feedback technologies can integrate the sense of touch to increase the immersivity of a certain experience. While useful across most ecosystems, at the moment its development is not considered crucial, aside from sectors where touch can be a key element of a product to be sold or purchased (such as in the case of retail and textile ecosystems), or where it represents an important component in highly specific training settings (such as in aerospace and energy renewables, where applying the correct pressure may be a critical factor). Finally, advancements in audio hardware can be critical only in these ecosystems that heavily rely on content, and that, therefore, need to increase its fidelity and immersivity; or in ecosystems such as proximity, social economy, and civil security, where situational awareness and high-quality sound analysis are a core component.

2.3.2. Software needs

Software needs, presented in Table 6, regard the existing demand for specific pieces of software dedicated to various operations and activities required for creating content, and developing applications analysing data through XR technologies. The table presents an overview of the most important software needs identified, together with a short description, and indicates which needs have been found to be critical for current deployment and/or future uptake of XR in each ecosystem.

¹⁰⁶ Valliammai, V., Sandhya, K., Harshitha, V.L., Podili, P.P. and Basha, N.K., (2023), *Cloud-Based Intelligent Virtual Try-On Using Augmented Reality*, In Handbook of Research on Deep Learning Techniques for Cloud-Based Industrial IoT (pp. 61-78), available [here](#).

Table 6. Software-related needs

Need	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Development tools	Tools and platforms such as software development kits necessary to developers to create their XR applications				x			x	X	x	x				x
Content creation software	Set of software such as 3D models and video editing tools used by content creators to develop and produce new XR content				x					x	x		x	x	
User interface and user experience tools	UI and UX are fundamental elements of an intuitive XR solution		x	x	x		x						x	x	x
Simulation and rendering software	Graphic engines used to render high-quality graphics in real time				x							x			
Tracking and gesture recognition software	Software required to properly register and process inputs coming from tracking and gesture recognition hardware				x							x	x	x	
Analytics and data visualisation software	Used to track user behaviour and improve user experience	x		x											x

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

Differently from what emerged from the section above, **software needs seem to be less cross-sectoral in nature** and more linked to the specificities of each ecosystem analysed.

The software advancement that has been marked as critical in the highest number of ecosystems regards user interface and user experience tools. Developing a seamless and easy-to-use interface is a crucial aspect in the success of any given XR application, when targeting both end consumers and professionals. As XR technologies mature, aspects, such as UX and UI, gain more importance to offer a fully-fledged high-quality experience. Therefore, tools, such as visual design and prototyping software, are increasing in demand from studios, so that they can integrate and design intuitive navigation, clear visual cues, and engaging graphics in a faster and smarter way. More generally, the need for more and better development tools (i.e., software used by developers to easily create applications and experiences), such as game engines, 3D modelling software, and software development kits (SDK) is relatively widespread (six ecosystems). These tools are in fact fundamental for a variety of tasks, such as content creation, testing and debugging, performance optimisation, or even collaboration between different team members.

Need for customisation of VR training in wind energy

The key barrier preventing the broader adoption of VR training in the wind energy sector of the renewable energies industrial ecosystem seems to be the need for the customisation of such solutions, which are expensive.¹⁰⁷ While standardised training does exist in the wind energy sector – they are regulated by the Global Wind Organisation (GWO) –, VR training solutions have largely been customised for individual customers. In other words, XR deployment has depended on the openness of the companies active in the sector to engage with such solutions. However, customised solutions require a lot of time and money to perfect, thus, excluding smaller firms that cannot invest such resources. Hence, VR-based training in the wind energy sector have largely remained limited to large firms, such as Siemens Gamesa. On this matter, Kanda – the developer for Siemens Gamesa's customised solution for VR training in Denmark – are currently developing a potentially disruptive new solution. They are planning to launch a subscription-based model for certain GWO courses, which would reduce the cost of entry significantly. Note, however, that the argument of cost versus benefit more broadly also applies to other sectors within the industrial ecosystem.

Source: stakeholder consultations with sector experts.

Content creation software is generally considered to be of high enough quality, or not crucial enough to disrupt the ecosystem in case of advancements, in most of the ecosystems analysed. Exceptions are those sectors that rely more heavily on interaction with consumers (cultural and creative, retail, textile), or with personnel for training purposes (mobility-transport-automotive). A similar scenario is found with regard to tracking and gesture recognition software (see considerations under Section 2.3.1 above about advanced tracking hardware). Analytics and data visualisation software are critical in those ecosystems where integrations of XR with big data can provide useful insights and detailed flow information (see box on tourism below). Finally, simulation and rendering software is critical only in two sectors, which would benefit from improved capabilities to render XR content in real time, to create better experiences or videogames in the cultural and creative ecosystem, or to develop applications in the civil security domain.

Data flow integration in the tourism ecosystem

The analysis of big data is in especially high demand in the tourism sector, as a plethora of different sources, such as social media, user preference, and travel history, can help hotels and tourist destinations to tailor and personalise their offer to result in more appealing to potential customers. This is useful in marketing and advertising applications, where big data can be used to target tourists with personalised campaigns, which can be delivered and enhanced through XR

¹⁰⁷ Future Visual (2022), *Why virtual reality is the future of wind turbine training*, available [here](#).

technologies to increase their effectiveness.¹⁰⁸ With the increase of this integration between big data, AI algorithms, and XR technologies, tourism destinations have the potential to take these experiences a step further, creating infrastructures of smart destination management. These would optimise tourism resources and infrastructure, by analysing data on tourist flows, travel patterns, and attraction popularity. XR technologies could be integrated into such a system, providing real-time information on traffic flows, next-generation wayfinding applications highlighting and describing nearby attractions, and signal to tourists the safest/less crowded paths to reach their destination.

Source: stakeholder consultations with sector experts.

2.3.3. Infrastructure needs

This subsection refers to industrial needs regarding the IT infrastructure required for the proper functioning of XR technologies and their integration with other technologies. Infrastructure is understood as those virtual and physical components that play a role in IT and IT-enabled operations.¹⁰⁹ The table presents an overview of the most important infrastructure needs identified, together with a short description, and indicates which needs have been found to be critical for current deployment and/or future uptake of XR in each ecosystem.

¹⁰⁸ See Rauschnabel, P. A. (2022), *XR in tourism marketing*, in Buhalis, D., Encyclopedia of tourism management and marketing, available [here](#).

¹⁰⁹ See Gartner glossary, available here: <https://www.gartner.com/en/information-technology/glossary/it-infrastructure>

Table 7. IT infrastructure-related needs

Need	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Low-latency connectivity, 5G/6G	High-speed and low-latency connectivity, possibly through new generation 5G and 6G infrastructure, needed for data transfer and communication	x			X					x		x			
Standards and protocols	Industry-wide standards required to ensure interoperability between XR solutions			x			x	X	x	x	x	x	x	x	x
Infrastructure for integration with blockchain	Infrastructure such as blockchain network, decentralised storage, identity/access management to facilitate the integration of XR with blockchain technologies	x			X		x				x				
Cloud computing services	Infrastructure needed to process and analyse large amounts of data generated by XR applications	x					x			x					x
Edge computing	Distributed computing architecture reducing latency and improving performances	x													x
Sensors (external)	Sensors external to the XR device, to be integrated with the XR solution and, for instance, enhanced through AI			x											
Integration with existing IT systems	Infrastructure required to integrate XR with existing enterprise systems such as enterprise resource planning (ERP), customer relationship management (CRM), or supply chain management systems			x			x		x		x				x

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

In the case of infrastructural needs, the major trend emerging is the **cross-cutting relevance of standards and protocols**. Common standards are “technical specifications defining requirements for products, production processes, services, or test methods”¹¹⁰ which, in the case of XR, can regard technical specifications in hardware (display resolution, tracking technology), and software (platform requirements, communication protocols). They are also understood as guidelines and best practices, to ensure the quality and interoperability of hardware and software products. The development of proper industry standards is being led by initiatives, such as OpenXR, WebXR, and the IEEE VR and AR Standards Working Group.¹¹¹ The cross-sectoral nature of this need is due to various reasons. Standards would facilitate the development of XR applications and distribution for multiple devices – whereas, at the moment, hardware manufacturers often use their own proprietary systems, complicating the porting of applications from one software ecosystem to the other. Moreover, they would ensure proper interaction between XR and close emerging technologies (such as blockchain, AI or 5G), as well as facilitate its integration with existing systems and technologies – a crucial step, especially for businesses interested in using immersive technologies to renew their workflow. Therefore, improved interoperability would significantly facilitate XR studios in developing and monetising their XR products, as well as cutting costs for XR integration.

The problem of standards is closely related to the second and third most mentioned infrastructural needs across ecosystems, that is the integration with existing IT systems (five ecosystems out of 14), and integration with blockchain technologies (four out of 14). In the first case, the cause for issues is the fact that most companies, when deciding to start using XR solutions in their everyday work, already possess various IT tools and architectures – such as ERP, CRM, or supply chain management systems. Therefore, the seamless integration of these tools with the new XR solution is a crucial criterion element, which can result in high costs, especially in ecosystems where other technologies play an important role. This is the case, for instance, of the construction, electronics, energy-renewables, and mobility-transport-automotive ecosystems. Blockchain technologies, on the other hand, are particularly useful when it comes to data privacy and security due to their nature of distributed ledger systems (aerospace and defence, mobility-transport-automotive ecosystems), or when NFTs and other forms of transactions through cryptocurrency are especially important (cultural and creative ecosystem).

The need for low-latency connectivity or integration with 5G/6G, while clearly being a cross-cutting development, which would facilitate streaming operation or data transfer, is considered critical only in three ecosystems. There can be at least two explanations for this, mentioned by stakeholders interviewed: on the one hand, many applications work fairly well with current systems and, while certainly benefitting from a connectivity upgrade, would not be revolutionised by it. On the other, connectivity is crucial only in applications that require high efficiency and fast response rates (such as in defence or civil security contexts), or where streaming activities are an important way for content distribution (for instance, VR gaming streamers in the cultural and creative ecosystem).

Offline training in the renewable energy ecosystem and offline applications for the defence ecosystem

A unique need for technological advancement of the energy renewables ecosystem is the need for an option to run multi-participant VR-based training sessions offline. The offshore wind energy sector requires workers to perform their duties in remote locations. While VR-based training can replace some real-life offshore trainings with virtual onshore ones, it is conceivable that some training might still have to occur offshore. However, there, too, might be some training run virtually, to reduce safety risks. What is problematic is that, oftentimes, offshore locations lack the reliable internet access necessary to run collaborative training with several participants. Hence, if such

¹¹⁰ European Commission (2022), [European standards](#).

¹¹¹ Open XR website: <https://www.khronos.org/openxr/> ; WebXR website: <https://immersiveweb.dev/> ; IEEE website: <https://sagroups.ieee.org/2048wg/>

collaborative training were possible without the need to be connected to the internet, more use cases for VR-based training would be unlocked.

Similar to the renewable energy ecosystem, offline XR applications would be valued by the defence ecosystem as well. A key need for the further deployment of XR in the sector is ensuring the security of data, due to the sensitive nature of the sector (involving national secrets and military strategies). Using applications, be it VR training, or AR on field operations, offline would offer a higher level of protection against cyber threats, and, according to some interviewees, is a key condition for their organisations/clients to further deploy XR solutions.

Source: stakeholder consultations with sector experts.

Cloud computing services, and edge computing, are infrastructures with the potential to substantially increase the volume of data processed per second (and are therefore important in sectors, such as tourism, where visualisation of tourists' data can lead to quicker insights and improved customer experience), and the computing power available. Moreover, they are particularly important for integration of next-generation AI technologies in the XR ecosystem, making them critical in sectors, such as electronics, or aerospace and defence.

2.4. Barriers to the adoption of XR at a large scale

In this section, we describe the main barriers, identified during this study across the 14 industrial ecosystems, faced by producers and/or users of XR technologies that hinder further technological uptake of XR technologies. We place these barriers into the following five main categories: 1) technological; 2) business; 3) financial; 4) societal; 5) legal barriers. The rationale for this categorisation comes from the need to comprehensively address the principal domains where barriers may arise. Moreover, such a structured approach has previously been proposed and used in studies approved by the Commission.¹¹² For each category, we based the identification of barriers on desk research and findings deriving from interviews with stakeholders. We then conducted a cross-ecosystem analysis to assess, for each ecosystem, the relevance and importance of each identified barrier. Such an analysis included, once descriptions of single ecosystems were concluded, an internal focus group discussion to ensure consistency of findings. The degree of impact was then judged by the project team based on this discussion and on the evidence collected. While describing the main trends having an impact on the XR ecosystem, as a whole, we present, in textboxes, specific examples or peculiarities coming from single ecosystems. As for needs in Section 2.3, these specific examples do not necessarily represent ecosystem-wide trends; rather, they exemplify how some of the needs we identified can translate into practice.

2.4.1. Technological barriers

Technological barriers are closely linked to the needs for the further uptake of the technology presented in Section 2.3 above. Table 8 lists the main high-level challenges that have been identified and flagged throughout various of the 14 industrial ecosystems analysed, providing an indication of the degree of impact in each of them.

¹¹² Ecorys (2022). The Virtual and Augmented Reality Industrial Coalition – Strategic Paper. Available here: <https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1>

Table 8. Technology-related barriers

Barrier	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Standardisation	Lack of interoperability within the XR ecosystem and in relation to other relevant technologies, leading to reduced innovation and additional costs	High	Low	High	Medium	High	High	Medium	Medium	High	Medium	High	Medium	Medium	Medium
Hardware	Issues related to the current status of XR hardware, such as accessibility, usability, comfort, reliability	Low	Medium	Medium	High	Medium	High	Medium	High	High	High	Medium	Medium	Medium	Low
Software	Issues related to the lack or inadequateness of existing software/platforms to perform specific tasks or use certain XR solutions	Medium	High	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Infrastructure	Difficulties in making the most out of XR technologies due to technological infrastructure limitations	Medium	Low	Medium	Medium	Low	Medium	High	Medium	Medium	Medium	Low	Medium	Medium	Medium

Source: Authors' own elaboration - qualitative assessment based on findings emerging from ecosystems analyses.

Generally, stakeholders across many ecosystems underlined that **progress in terms of hardware is still being expected**, and could significantly increase the appeal of XR for consumers and businesses. While XR technologies are considered relatively mature and past their infancy days, from a technical point of view, various technological challenges still persist, and have the potential of limiting further uptake and deployment.¹¹³ The desired progress needs vary depending on the ecosystem, and range between better resolution for applications relying on image fidelity to better battery life and more headsets comfort. Even in cases where interviewees declared that the core of the technology “is already here”, expectations for the future are high.

Precision and accuracy in the mobility-transport-automotive industrial ecosystem

The current technological capabilities of XR tools present substantial challenges for the widespread adoption within the mobility-transport-automotive industrial ecosystem¹¹⁴. This ecosystem demands high levels of precision, yet the existing state of XR technology struggles to deliver accurate real-time impressions of material quality and interactions under varying light conditions. As a result, enhancements in the visual aspects of XR, such as colour correction and brightness, remain necessary. Moreover, the size dimensions of the equipment, lens quality, and perspective distortion pose additional obstacles. Another relevant factor in the automotive manufacturing process is the extensive volume of data involved, which necessitates optimisation for effective XR utilisation. Regrettably, the present state of XR lacks the capacity to manage this degree of complexity. Likewise, in the adoption of XR solutions present security concerns related to the storage of sensitive information on external servers.

Source: stakeholder consultations with sector experts.

One of the most important barriers, ranked as “Medium” or “High”, in terms of impact in most ecosystems, regards ongoing **standardisation efforts – or their lack thereof**, as emerged from findings of the section above on industry needs. Current deficiencies in the EU (and at the global level) regarding standards often result in issues related to interoperability, which hinder the possibility of developing new applications or easily monetise existing applications. Different hardware and software providers offer their proprietary solutions, which may not be compatible with one another. This complicates actions aimed at developing common standards, and often results in sub-optimal performances of the final piece of content.

With regards to hardware, software, and IT infrastructure, more details are provided in the section above on needs for specific details. When considering the importance of these elements as barriers, it is interesting to note how **hardware-related issues** tend to be perceived as more important or impactful, when compared to the other two categories – showing how XR, while evolving, is still far from its full maturity. Therefore, problems, such as lack of reliability, size, and comfort of headsets, or the sheer computational power needed to properly operate XR solutions still need to be solved. With regards to software, it is ranked as a “Medium” problem in almost every industrial ecosystem. Finally, technological infrastructure should be strengthened to ensure proper interaction between XR and close emerging technologies (such as blockchain, AI, or 5G), as well as facilitate its integration with existing systems and technologies – a crucial step, especially for businesses interested in using immersive technologies to renew their workflow.

¹¹³ Various studies and reports focus on existing technological challenges across ecosystems. For instance, see European Commission (2023), *Extended Reality – Opportunities, success stories and challenges (health, education)*, available [here](#); or Minopoulos, G., Psannis, K. E. (2023), *Opportunities and Challenges of Tangible XR Applications for 5G Networks and Beyond*, in IEEE Consumer Electronics Magazine, vol. 12, no. 6, pp. 9-19, 1 Nov. 2023, doi: 10.1109/MCE.2022.3156305; or Ziker, C., Truman, B., Dodds, H. (2021), *Cross Reality (XR): Challenges and opportunities across the spectrum*, in Ruoo, J., Winkelmann, K., Innovative learning environments in STEM higher education, available [here](#).

¹¹⁴ For an overview, see Boboc, R.G., Gîrbacia, F. and Butilă, E.V., (2020), *The application of augmented reality in the automotive industry: A systematic literature review*, available [here](#).

Reliability of digital twins of offshore wind turbine blades

A technological barrier specific to the renewable energies industrial ecosystem pertains to the reliability of XR applications that are designed to remotely monitor wind turbines. In particular, solutions, such as the digital twin of a wind turbine blade, as developed by project ReliaBlade,¹¹⁵ would, if scaled up, need to be able to reliably monitor all three blades of large offshore wind farms. This necessitates the need for an automatised solution that is not prone to sending out frequent false alarms. However, Kim Brenner of ReliaBlade holds that digital twin solutions still remain rather experimental, and have not yet achieved the appropriate levels of robustness and reliability.

Source: stakeholder consultations with sector experts.

2.4.2. Business barriers

Business barriers are difficulties related to specific conditions of the XR market that hamper the possibility for businesses to properly monetise XR solutions, or to effectively integrate them into their workflow. The table below presents the most important business barriers.

¹¹⁵ Project website available [here](#).

Table 9. Business barriers

Barrier	Short description	Ecosystem													
		Aerospac e and defence	Agri- food	Construc tion	Cultural and creative industrie s	Digital	Electronics	Energy- intensive industries	Energy- renewables	Health	Mobility- transport- automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Dominance of non-European actors	Excessive influence of non-European actors in key areas of the whole XR ecosystem, leading to limited competitiveness and influence.	High	Medium	Low	High	High	High	Medium	Low	Medium	Medium	Medium	Low	Low	Low
Market fragmentation	Difficulties in upscaling XR technologies across different Member States (due to regulation, preference for national markets)	High	Medium	High	High	High	High	Medium	Low	Medium	Low	Low	Low	Medium	Medium
Business models	Limited opportunities to monetise XR solutions and applications due to lack/ineffectiveness of existing business models	Low	High	Low	Medium	Medium	Medium	Medium	Low	Medium	Low	Medium	Low	Medium	High
Costs	Excessive costs in adopting XR technologies from the side of business (implementation in the workflow) and consumers (purchase of required hardware)	Low	High	Medium	Medium	Low	Low	Low	Medium	High	Medium	Medium	Medium	Medium	Medium
User base	Limited user base interested in integrating XR technologies or using them as final consumers	Low	Medium	Medium	High	Medium	Low	Low	High	Medium	Low	Medium	Low	High	Medium

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

One of the most relevant challenges related to the business environment specifically regards the EU – rather, the **relative lack of importance of EU players** as opposed to the enormous influence that non-EU actors exert on the global market. American players dominate the platform landscape (at least in the Western market), with distributors, such as the Oculus Quest Store and Steam. The situation is more varied when it comes to hardware, with the US, Japan, China, and South Korea housing the biggest manufacturers (such as Oculus, Sony, HTC, Pico, etc). This is confirmed by Delphi survey respondents, most of whom agree (56% or nine out of 16) or strongly agree (25% or four out of 16) that adoption in Europe appears to be slower, compared to North America and Asia. This dominance of non-EU players has direct consequences on content production and distribution, often limiting creators and preventing them to shape the market in concert with policymakers. To increase the presence of European companies in the XR industry and virtual worlds, investment and promotion of EU-based services are needed to create a highly competitive ecosystem aligned with EU values in terms of commercial, ethical, and quality aspects. It would be foremost important to support innovation through more Horizon funding, taking a multidisciplinary approach for application areas in the virtual worlds (including XR, AI, 5G, and cloud) (81% agreement from Delphi survey respondents (13 out of 16 agreed or strongly agreed). As noted by Delphi survey respondents, the EU has the potential to lead the industry by establishing frameworks and standards for the future virtual worlds similar to how HTML (HyperText Markup Language) did for the internet. One opportunity is the creation of a quality standard label that ensures end-users of the safety and privacy of their neuro data, which could help the EU to become a global sector leader.

Monetisation difficulties in the tourism and cultural and creative ecosystems

In specific circumstances, monetisation opportunities for European content creators can be thwarted or removed altogether due to strategic or business decisions implemented by the main platforms that distribute digital content. The most important ones, based in the US, are the Oculus Quest Store and Steam. Both took the executive decision of removing the possibility for creators to upload paid video content – and, therefore, to permit only the presence of videos available for free. The decision was taken as videos do not generate revenues for these platforms (as they do on other platforms, such as YouTube), but are rather a way to showcase content available on the platform. However, XR studios that produced and sold 360 degrees videos suddenly lost an opportunity to monetise their work, as developing a dedicated application with in-app purchase options would require extensive resources and encounter interoperability issues across platforms.

Source: stakeholder consultations with sector experts.

A concern that is more widely perceived as problematic across industrial ecosystems regards the **XR market fragmentation**. It is still not possible to talk about a true EU market, as current differences in regulation, traditional mindsets, and the still widespread tendency to favour national industries and entities over other EU ones, fragment the European landscape into its smaller, national, or even regional/local components. This situation leads to difficulties in upscaling successful XR solutions and establishing businesses on a cross-national basis. Stakeholders from many ecosystems with a strong international dimension flagged this issue in relation to XR technologies. Experts surveyed in the second Delphi survey round also rated likelihood (81%, or 11 out of 16 respondents) that successful adoption of the XR technologies and the virtual worlds¹¹⁶ in the EU are hindered by a **lack of strategic thinking and vision** to be high. This is correlated with the opinion of Delphi survey respondents that there is a **lack of a central body** that could help unify access to resources and information that aids those creating legal frameworks and training plans (63% of respondents or 10 out of 16 agreed or strongly agreed with this statement).

¹¹⁶ The survey questionnaire used term metaverse, but the report was revised to be in line with the vocabulary used in Communication adopted by the European Commission on 11 July 2023, setting out a strategy focusing on Web 4.0 and virtual worlds.

XR market fragmentation in the health sector¹¹⁷

The lack of widely accepted standards in the healthcare ecosystem is hindering system interoperability, increasing development and testing costs, and limiting innovation. Healthcare organisations are faced with the challenge of having to create custom solutions for each system they want to integrate, resulting in higher costs and longer development cycles. This fragmented environment makes it difficult to share information between different systems, leading to inefficiencies and reducing the overall quality of care. This is particularly worrying in the fast-moving healthcare industry, where timely access to accurate information is crucial to patient outcomes. European governments, healthcare providers, and technology companies are increasingly recognising the importance of standards in enabling interoperability, reducing costs, and promoting innovation in the healthcare ecosystem. The European Interoperability Framework (EIF)¹¹⁸ is one example of an initiative that is working to develop standards and guidelines to support the seamless exchange of information between different systems and technologies. By addressing this issue, they aim to improve the quality of care, and ensure timely access to accurate information, which is essential in the healthcare industry.

Source: stakeholder consultations with sector experts.

The existence of **viable business models** for the proper monetisation of XR solutions, and the possibility of creating and finding new, innovative ones, is a particularly important factor for the business environment. In most ecosystems, this issue is indicated as of “Medium” or “Low” importance. This is due to the fact that XR is no longer considered to be a new technology, and successful business models have already been established. Still, many businesses are not aware of them, or are suspicious towards the return on investments related to XR technologies.

Lack of suitable business models in the agri-food ecosystem

XR technology, despite its potential benefits, faces multiple obstacles to widespread adoption within the agricultural and food industrial ecosystems. One of the primary obstacles is the absence of appropriate business models that can justify the costs associated with the technology's adoption. The initial expenses of implementing and maintaining XR solutions can surpass the anticipated gains in productivity and efficiency. Additionally, the agricultural sector struggles with a persistent lack of digital literacy among its workforce, which further slows down the broader deployment of XR technology. This knowledge gap can impede the effective utilisation of XR applications and diminish the potential return on investment. Consequently, fostering digital literacy and developing tailored training programs for the agricultural community will be crucial in overcoming this barrier.

Source: stakeholder consultations with sector experts.

Costs associated with developing and implementing immersive technologies into traditional workflows are still considered a problem in various ecosystems. However, the situation has been improving over the last years, due to the significant reduction in the price especially of low- and medium-end headsets, which allows consumers and smaller businesses to consider the purchase of XR solutions.¹¹⁹ However, costs for users can easily amount to more than the purchase sum, as for example, powerful computers and relevant hardware (e.g., headsets or sensors) need to be first purchased and then properly maintained. Moreover, integrating the XR solution with the existing digital workflow of a company can take additional time and resources, which makes the initial investment in XR a barrier often too high for SMEs to surpass.

Issues related to the **limited user base** seem to be considered as less problematic than others, as well. This is due to the fact that XR technologies are nowadays better known by stakeholders and businesses, and awareness about the benefits is higher. However,

¹¹⁷ Description is based on interviews and Visionary Analytics, IDEA Consult, Boel, C., Dekeyser, K., Depaepe, F., et al., Extended reality: opportunities, success stories and challenges (health, education): final report, Publications Office of the European Union, 2023. Available [here](#).

¹¹⁸ Website available [here](#)

¹¹⁹ A prime example of this trend has been the Oculus Quest 2, a wireless and standalone headset with low-medium performance which sold at around EUR 350 in Europe.

especially ecosystems that heavily rely on consumers and XR technologies going mainstream (such as the cultural and creative or the textile sector) still find the problem of the thin consumer base to be highly important.

2.4.3. Financial barriers

This category of barriers regards access to finance, either public or private, and the market readiness of XR technologies.

Table 10. Financial barriers

Barrier	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Access to funding related to content development	Limited access to public and private funding opportunities dedicated to developing new content	Low	Medium	Low	High	Medium	Medium	Low	Low	Medium	Low	High	Medium	Medium	Medium
Access to funding related to commercialisation and scaling-up	Limited access to risk financing for upscaling XR solutions and bring them to the market	Medium	Medium	Medium	Medium	High	High	Low	Low	Medium	Low	High	Medium	Medium	Medium
Access to funding related to R&D and R&I	Limited access to public and private funding opportunities aimed at developing innovative XR solutions or XR-related processes	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium	Low	High	Medium	Medium	Low
Uncertain market potential	Lack of strong data evidence base and technological track record proving XR potential in terms of ROI	High	High	Medium	Medium	High	Medium	Medium	Low	High	Low	Low	Medium	Medium	Medium

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

Overall **difficulties with regard to access to funding** are known within the XR community and have been highlighted in different studies.¹²⁰ Public funding at EU- and national-level is often insufficient and not tailored to the specific needs of XR technologies, often mixing creative and artistic elements with their technical dimensions. Stakeholders often provided positive feedback with regard to EU-level funding opportunities, such as Creative Europe. However, they underline how these opportunities should receive more abundant budgets to reduce the fierce competition around them and streamline administrative requirements to the highest extent possible. In fact, especially SMEs and start-ups struggle to find and allocate the resources necessary to apply for public opportunities. Interestingly, these observations regard both EU- and national-level funding opportunities. Access to private opportunities, on the other hand, is often caused by private investors' risk aversion, especially in the EU, towards XR (see below). This results in fewer possibilities for innovative studios, which face recurring problems in obtaining financing in Europe. During interviews with companies in the proximity, social economy, and civil security sectors, a common theme emerged regarding the need for more financial support and a cohesive platform for XR technology companies. These companies expressed that the current funding initiatives are insufficient in providing long-term support and emphasised the importance of easier access to funding.

The table above distinguishes **access to funding depending on the final purpose**. The importance of each category varies across ecosystems, especially in relation to the type of applications and solutions that are more in demand in each of them. Therefore, financing related to content creation is a particular problem in an ecosystem, such as the cultural and creative one, while commercialisation and scaling up financing opportunities are more in need in technology-intensive ecosystems, such as the digital, electronics, and proximity ones. Funding related to R&D and R&I has been found to be a high-impact challenge only in the proximity sector, which is generally underdeveloped in comparison to others and faces numerous challenges, as a whole. This is in line with the idea that emerged from various sources and stakeholders, that XR technologies are fairly developed and mature from a purely technological point of view (despite the current limitations still being impactful, as noted in Section 2.3). Therefore, while remaining relevant, lack of funding opportunities in research, innovation, and development are relatively less impactful than others.

The remaining **uncertainties regarding the market potential** of XR are a wider problem that affects various ecosystems. Data about the return on investment of XR are not definitive and investors are often unwilling to support innovative XR studios, knowing that their initial expense may not be compensated with future gains. Further maturing of XR solutions as market products may improve this situation over time. As mentioned above, this is a specifically European problem affecting not only XR technologies, but the overall tech market. Due to the difficulties in identifying and obtaining proper funding from European private entities, many European start-ups interested in scaling up their business are led to look for VCs, angel investors or seed funding outside of the EU, particularly in the US and in North America. This can undermine EU efforts to strengthen its own innovation capacity and increase its dependence on external sources of technology and capital.

High volumes of risk financing for the digital and electronics ecosystems

While commercialisation and scaling-up financing is, to some extent, a barrier for most ecosystems, the required volumes are comparatively higher for the development of core hardware, such as VR headsets, AR glasses, etc., as well as for the development of platforms for developers and/or end users, such as virtual worlds. European SMEs are proving that in terms of R&D, technological development, and capabilities successful solutions are emerging in those areas. However, many innovative start-ups are either purchased by larger companies, or are struggling to raise high-risk financing to scale their activities. The XR financing analysis in Section 2.1 gives some indication of the successful EU-based companies in fundraising, as well as the gap in the total funding raised in the EU, compared to other leading ecosystems in terms of XR development.

¹²⁰ For an overview and examples of other reports, see Ecorys (2022), AR/VR Industrial Coalition.

Source: stakeholder consultations with sector experts.

2.4.4. Societal barriers

Societal barriers mostly relate to the education of users and professionals in the context of XR technologies, with the potential of hampering or slowing their acceptance in society and further uptake.

Table 11. Societal barriers

Barrier	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
User awareness	Lack of awareness of XR technologies (in terms of benefits and potential) from the side of professionals or final users.	Medium	High	Medium	Medium	Medium	Low	High	High	Medium	Low	Medium	High	High	High
User acceptance	Resistance from users in transitioning from a traditional to an XR solution	Medium	High	High	Medium	Medium	Medium	High	High	High	Medium	Medium	Medium	Medium	Medium
Lack of talent with technical expertise	Lack of staff with the required technical expertise to develop or provide assistance to businesses in installation and operation of XR technologies	Medium	Medium	Medium	Low	Medium	Medium	High	High	High	High	Medium	Medium	Medium	Medium

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

Users' awareness (both in terms of consumers and businesses integrating XR) refers to at least two aspects: 1) awareness of the benefits of XR, which is often overlooked as a technology, or considered only for its promotional value, as opposed to the plethora of its different applications; 2) awareness of the specificities of the various XR technologies and of the potential difficulties that can be encountered during the implementation stages. This last aspect has been mentioned by several stakeholders, who often select their clients based on their understanding of how the technology can practically solve the specific issue(s) they want to tackle. Lack of this general understanding can lead to misuse of XR, as well as to unsatisfactory results or poor assessments of the resources and efforts needed to implement it. Most of the experts from the second round of Delphi survey also tend to agree (94%, or 15 out of 16 rated this as very likely or likely) that people are unaware of the possibilities with XR and virtual world¹²¹ technologies, or have misconceptions, due to a lack of education and understanding.

Problems with social acceptance are especially high in ecosystems where professionals need to transition from traditional ways of conducting work-related tasks (such as working on a construction site or in a manufacturing plant), to the use of XR technologies. Whenever tasks involving security issues are involved, reluctance increases further.

Need for further clinical research in the healthcare ecosystem

To ensure the safety and effectiveness of XR technologies in the health sector, clinical trials and studies are needed. These trials and studies involve testing XR technologies on patients to assess their efficacy, identify potential side effects, and evaluate their impact on patient outcomes.¹²² The results of these studies inform decisions about whether to use the technology in clinical settings. While interviewed stakeholders acknowledge the promising potential of XR technologies in healthcare, they also caution that careful research and analysis are required to fully understand their impact on an individual's psychological and physiological well-being. The efficiency of these technologies remains unclear, and further studies are needed to ensure their safety and effectiveness.

Source: stakeholder consultations with sector experts.

The last challenge identified regards the talent, that is professionals and specialised staff working in the XR sector. Across various ecosystems, the number of professionals with the right set of skills to develop and implement XR solutions is perceived to be sub-optimal, with the sole creative and cultural ecosystem marking the issue as “Low”. Educational efforts to include XR teaching in university courses and increased opportunities in terms of training modules would be beneficial to improve the situation further.¹²³

2.4.5. Legal barriers

These barriers regard challenges linked to the existing legal framework around XR technologies and to various uncertainties still in existence.

¹²¹ The survey questionnaire used term metaverse, but the report was revised to be in line with the vocabulary used in Communication adopted by the European Commission on 11 July 2023, setting out a strategy focusing on Web 4.0 and virtual worlds.

¹²² An overview of challenges can be found in Garrett B, Taverner T, Gromala D, Tao G, Cordingley E, Sun C. (2018) *Virtual Reality Clinical Research: Promises and Challenges*, available [here](#).

¹²³ An analysis of the importance and impact of education efforts regarding XR can be found in Ecorys (2022), AR/VR Industrial Coalition.

Table 12. Legal barriers

Barrier	Short description	Ecosystem													
		Aerospace and defence	Agri-food	Construction	Cultural and creative industries	Digital	Electronics	Energy-intensive industries	Energy-renewables	Health	Mobility-transport-automotive	Proximity, social economy, and civil security	Retail	Textile	Tourism
Intellectual Property management	Obstacles faced by individuals or organisations in protecting their IP rights, such as: 1) unclear legal framework; 2) costs of IP protection; 3) unclarity in identifying infringements	Medium	Low	Medium	High	Low	Medium	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium
Ethical issues	Fallacies and uncertainties of the current regulatory framework in terms of ethical issues.	Medium	Low	Low	High	Low	Low	Low	Low	High	Low	High	Low	Low	Low
Cybersecurity	Difficulties in developing a proper security system against data breaches and other threats	High	Low	Low	Low	Medium	Medium	Medium	Low	High	High	High	Low	Low	Low
Privacy and identity protection	Difficulties in properly protecting sensitive (personal) data belonging to users and collected by XR technologies	Medium	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium

Source: Authors' own elaboration – qualitative assessment based on findings emerging from ecosystems analyses.

Protection of IP rights is a crucial aspect, especially for creative professionals (see box below), which is still largely unaddressed.¹²⁴ The main issues in this context regard two aspects: 1) unclear legal framework, which leads to difficulties in identifying the IP rightholders, as well as enforcing the existing regulation and detecting cases of infringement; 2) costs and resources necessary to businesses and professionals to properly understand and set up IP right protection management systems.

IP rights protection in the cultural and creative ecosystem

Protection of IP rights is a particularly relevant element in the cultural and creative ecosystem for at least two reasons. On the one hand, in this ecosystem, many freelancers and independent professionals develop and monetise their content on the internet. It is, therefore, particularly difficult to control the unauthorised use and distribution of XR content, especially due to the ease of digital reproduction. Moreover, the often-unfair power balance existing between content creators and non-EU platforms distributing the content is a cause for unfair practices in terms of payment, content censorship, and IP rights management. On the other hand, the nature of the content produced (which may be video games, XR experiences, or pieces of art) often complicates establishing the clear ownership and control of a certain IP. This is caused by the number of stakeholders involved and the uncertainties left by many regulatory frameworks in the EU and at a global level, which do not properly define artistic content.¹²⁵ The fact that XR technologies are still in development exacerbates the problem, as standardised frameworks applying to all forms of XR content do not exist. Moreover, traditional copyright laws usually do not fully apply to XR content, due to its experimental nature.

Source: stakeholder consultations with sector experts.

Fallacies in the regulatory framework are also associated with various ethical implications of XR technologies.¹²⁶ Various dimensions fall under these ethical implications, including for instance health and safety risks linked to physical injuries or excessive use of XR content, psychological effects, and cases of discrimination, abuse, or toxic behaviour, while using XR content. All these elements are still largely unexplored, due to their complexity and novelty.¹²⁷ Policy interventions, in this sense, should take into account principles, such as transparency, fairness, accountability, and respect for human rights, and establish clear behavioural guidelines, to ensure XR technologies remain accessible and safe.

Security also relates to the protection of user's data generated from or collected through the use of XR against cyber-attacks and hacking.¹²⁸ This issue is especially important in ecosystems often operating with sensitive or confidential data (such as aerospace and defence or healthcare ecosystems). While this challenge has many technological components, it has a strong legal connotation, due to the links to XR's peculiar IP protection system (as mentioned in the textbox above), the unclear liability arising in case of data security breaches and the need to comply with existing regulation to ensure data protection is guaranteed.

Cybersecurity and sensitive data protection for aerospace and defence

The adoption of XR technologies in the aerospace and defence sector presents distinct challenges, primarily due to the critical nature of the information being handled. As these industries deal with national security concerns and highly sensitive data, stringent cybersecurity, and data protection standards are indispensable for the successful integration of XR solutions. Furthermore, ensuring the capability to operate XR applications in offline and wired environments, while preserving robust

¹²⁴ Kikkis, I. (2022), *Raising awareness on Intellectual Property for Creative Industries in the digital environment*, available [here](#).

¹²⁵ For instance, see Haper, A. (2021), *IP issues for artists and authors – the often-blurry line between copying and inspiration*, available [here](#).

¹²⁶ As emerged from stakeholder consultations. See also Vinders, J., Howkins, B. (2023). *Enhancing EU legal frameworks for Digital Extended Reality*, available [here](#).

¹²⁷ Kenwright, B., (2018), *Virtual Reality: Ethical Challenges and Dangers [Opinion]* in *IEEE Technology and Society Magazine*, vol. 37, no. 4, pp. 20-25, Dec. 2018, doi: 10.1109/MTS.2018.2876104.

¹²⁸ For an overview, see Qamar, S., Anwar, Z., Afzal, M. (2023), *A systematic threat analysis and defense strategies for the metaverse and extended reality systems*, *Computers & Security*, Volume 128, <https://doi.org/10.1016/j.cose.2023.103127>.

security measures, is of paramount importance, as current wireless technology can easily be detected and hacked.

Source: stakeholder consultations with sector experts.

A similar element regards the collection and use of **personal and sensitive data** belonging to users of XR technologies.¹²⁹ The range of data that can be collected by advanced XR technologies is vast and include biometrics, eye movements, gesture and posture, and reaction times to stimuli. A strong regulatory framework should be established to avoid misuse of these data, which can have medical or health-related implications.

2.5. XR-related opportunities for the EU industrial competitiveness

XR technologies offer a wide array of opportunities identified in this study to improve industrial competitiveness through various channels. Some of those include increased productivity (i.e., through remote collaboration), lower costs (i.e., reduction in the number of physical prototypes), higher precision (i.e., through AR-assisted operations in manufacturing), increased efficiency and effectiveness (i.e., in training under several industrial ecosystems, notably healthcare and Industrial ecosystems entailing manufacturing processes), enhanced environmental sustainability (i.e., through virtual prototypes and digital twins), enhanced collaboration and interactions (i.e., interdisciplinary collaboration focusing on virtual objects, virtual conferences), innovative sales and marketing options (i.e., virtual commerce, and marketing).

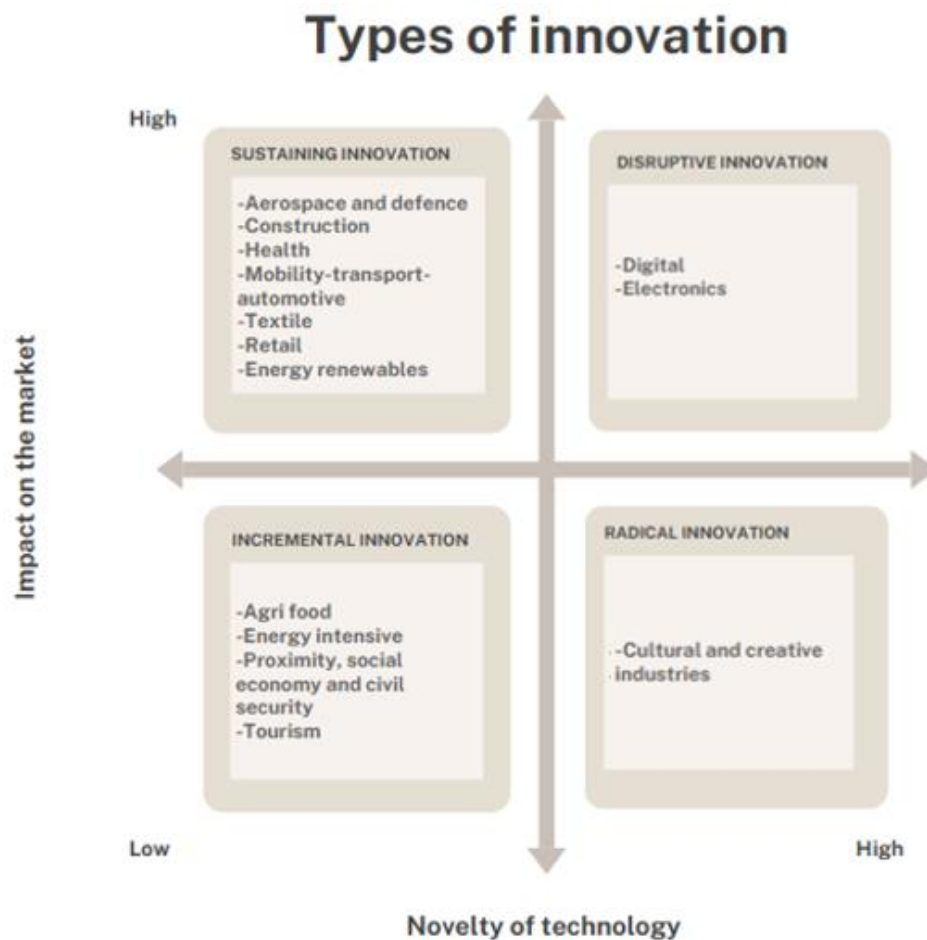
There is uncertainty on the future of XR technologies and the potential uptake of virtual worlds. The use of XR and virtual worlds could be optimised in combination with other emerging technological areas, such as artificial intelligence, blockchain, edge computing, and even brain-computer interfaces. This section focuses on the opportunity areas based on the existing technological development stage as reflected by existing applications and use cases of XR in different industrial ecosystems.

Based on the conducted research (i.e. interviews, Delphi survey, analysis of desk research findings), we identify the main types of innovation currently occurring in each industrial ecosystem. Those are categorised as **sustaining innovation** (an improvement on a product or service that aims to sustain the market position), **radical innovation** (a technological breakthrough that completely transforms an industry and creates a completely new market), **incremental innovation** (gradual and continuous improvements in products and services), and **disruptive innovation** (a technological breakthrough that disrupts the existing market). This categorisation is performed after answering two main questions for the most dominant set of application areas under the industrial ecosystem in question. Those questions are whether the innovation creates a new market, and whether a new technology is used.

It is important to note that the categorisation below does not focus on the type of innovation an XR process entails (e.g., whether XR completely disrupts a manufacturing process), but it is rather based on the end product or service the industrial ecosystem in question produces/offers.

¹²⁹ McGill, M. (2021), *Extended Reality (XR) and the erosion of anonymity and privacy*, available [here](#).

Figure 20. Types of XR enabled innovation in various industrial ecosystems



Source: authors' own elaboration based on different innovation taxonomies¹³⁰ - qualitative assessment based on findings emerging from ecosystems analyses.

The figure above illustrates the types of innovation enabled by XR in the industrial ecosystems. Our research has identified that innovation occurs in all industrial ecosystems, where XR technologies are deployed. A few ecosystems, typically those with low levels of digitalisation or have relatively low adoption of advanced technologies¹³¹ (with the exception of tourism), experience **incremental innovation**.¹³² XR solutions in those sectors tend to be implemented for marketing or professional training, leading to steady and gradual improvements in the ways products and services are developed and distributed. Use cases with higher potential market impact are tested in some cases, however, there is no sufficient evidence either on their high market adoption, nor their level of technological deployment. For instance, in the case of tourism, VR is frequently used for marketing purposes, and AR often enhances tourist visits to sites, museums, etc. enhancing the visitors' experience. However, more disruptive use cases, such as fully immersive VR tourism from one's couch, are not deployed to a large extent.

Sustaining innovation¹³³, similar to incremental, does not fully revolutionise the end product, but it does significantly contribute to the innovative process for the end product or service. A differentiating factor of the industrial ecosystems that are categorised here is that many of those sectors, already prior to the deployment of XR technologies were frequently

¹³⁰ Kylliäinen (2019), "Types of Innovation – The Ultimate Guide with Definitions and Examples", available [here](#).

Dieffenbacher (2023), "Types of Innovation: How the 4 Innovation Types Can Help your Business", available [here](#).

¹³¹ Advanced Technologies for Industry (ATI), available [here](#)

¹³² For full definition, see: Kylliäinen (2019), "Types of Innovation – The Ultimate Guide with Definitions and Examples", available [here](#). Dieffenbacher (2023), "Types of Innovation: How the 4 Innovation Types Can Help your Business", available [here](#).

¹³³ For full definition, see: Kylliäinen (2019), "Types of Innovation – The Ultimate Guide with Definitions and Examples", available [here](#). Dieffenbacher (2023), "Types of Innovation: How the 4 Innovation Types Can Help your Business", available [here](#).

using virtual 3D designs in their development process, and in some cases digital twins in their processes. This starting point is leveraged through the deployment of XR technologies, which are applied not only in marketing and training, but to a very large extent also in the actual conceptualisation, design, product development, and maintenance processes. This in many cases has led to significant product improvements with a large market impact. For instance, collaboration amongst professionals from different disciplines in the aerospace sector, for components that require high precision, has led to faster and more effective product development and troubleshooting.

The cultural & creative industrial ecosystem is classified as contributing to **radical innovation**.¹³⁴ The cultural and creative ecosystem, with gaming and entertainment applications on the forefront, is bringing completely reinvented immersive experiences to consumers. These experiences have been primary drivers of XR technology adoption in particular in the B2C markets, blurring the line between real and virtual worlds. Even though cultural and creative applications experience high market penetration, these currently to a large extent address an existing market demand, i.e., video games and movies becoming more immersive and interactive. This is the reason that the impact on the market is less significant, compared to digital and electronics industrial ecosystems.

Digital and electronics industrial ecosystems are responsible for the development of XR hardware and software. Within the electronics ecosystem, the development of XR hardware, such as headsets, has created a completely new product, that is in some cases replacing and in others complementing existing hardware. The **disruptive innovation**¹³⁵ arises from the combination of bringing a new technology (XR) into the ecosystem, and creating a new market segment for immersive experiences for personal and professional use. Also, in the case of the digital ecosystem, it provides the capabilities (i.e., software and tools) to create content for each of the other industrial ecosystems. New market trends are appearing within digital, such as platforms focusing either on the development of virtual content, or in the distribution of those to the end user.

This section is focusing on opportunities arising from the XR industry. While there is an innovative potential of the deployment of XR in all industrial sectors based on the innovation classification conducted above, it is noted that the technological novelty and impact to the market may vary. Taking into account the impact of XR on the market, as well as in terms of industrial competitiveness, and other parameters, such as positive societal outcomes this section identifies two types of industrial ecosystems, or specific segments of those that are considered as of high potential. These include ecosystems that are showing already relatively high uptake of XR technologies, in several segments of their value chains, from conceptualisation and development, to production and marketing, such as:

- Healthcare
- Construction
- Aerospace and Defence
- Automotive

In addition to the above, the following ecosystems based on the same parameters are also distinct in terms of their innovative and market potential:

- Digital
- Electronics
- Cultural and creative industries

¹³⁴ Idem

¹³⁵ Idem

In this case, one of the factors of the ecosystems' high potential is their B2C market. The target audience is not limited to a specific type of professional or sector, but products and services can reach the mass market. This entails tremendous opportunities, in terms of market adoption and shaping the future of the ways people socialise, entertain themselves, and conduct business (across business disciplines). In addition, grasping the opportunities within this ecosystem not only improves the EU's industrial competitiveness, but has an impact on the extent to which XR is deployed in line with the EU Declaration on Digital Principles and Rights.¹³⁶ Leveraging on the potential of digital, electronics and CCI ecosystems and ensuring the optimal development and deployment of XR within those, significant work is required for lifting the barriers they are facing and to address their needs. These elements are described more in depth in the previous sections 2.3 and 2.4. A quintessential factor for maximising the contribution to EU's industrial competitiveness is the availability and volume of high-risk financing.

¹³⁶ See: <https://digital-strategy.ec.europa.eu/en/policies/digital-principles>

3. XR- and virtual worlds-related public initiatives in EU and HEAC

At the strategic level, the European Commission does not identify XR as a separate technology field (there is no separate strategy for advancing XR). However, the Commission highlights the importance of XR via its close connection to the development of other innovative technologies, including the application of artificial intelligence. For example, cutting-edge technologies such as XR are seen as having a crucial role in fostering the digital transformation of businesses and the digitalisation of public services, thus contributing to targets of the 2030 Digital Compass: The European way for the Digital Decade.¹³⁷

Moreover, the Commission has also expressed its readiness to support the development of virtual worlds, laying the groundwork to structure the ecosystem. An example is the Virtual and Augmented Reality Industrial Coalition¹³⁸, first announced in 2020 in the Commission's Media and Audiovisual Action Plan¹³⁹, which brings together stakeholders from the key virtual worlds' technologies, and outlines a roadmap endorsed by over 40 EU organisations. Furthermore, in July 2023 the Commission laid out the foundations for a new European initiative on Web 4.0 and Virtual Worlds, which aims to achieve Digital Decade policy objectives through a controlled transition to web 4.0 and virtual worlds applications.¹⁴⁰ This initiative aims to support the development of virtual worlds, such as metaverses, which will, in turn, provide a myriad of possibilities within the industries and service sectors, the creative arts, and for citizens, as well as opportunities to address broader social challenges, such as health and smart cities.

Currently, at the European level, XR is supported through the Horizon Europe programme,¹⁴¹ activities of the European Institute of Innovation and Technology (EIT), and its Knowledge and Innovation Communities (KICs), in particular, the EIT Digital,¹⁴² through initiatives dedicated to encouraging collaboration in the European XR sector (VR/AR industry coalition, VR Media Lab), and the Creative Europe MEDIA programme, which supports immersive content development and creators.

To date, there has not been EU-level research to map initiatives fostering the deployment and uptake of XR technologies at the national level. One of the aims of this study is to close this gap by developing an inventory of public initiatives (i.e. policy measures, actions and plans, as well as their corresponding supporting instruments) aiming to foster the deployment and uptake of XR technologies in the EU, countries associated with Horizon Europe and third countries across all six continents.

The following sections present an overview of public initiatives in EU Member States and Horizon Europe associated countries (hereinafter abbreviated to HEAC). The initiatives are compared across three dimensions:

- Geographic distribution of initiatives (presence/absence of XR initiatives in certain countries/regions).

¹³⁷ European Commission communication of 9 March 2021 "2030 Digital Compass: the European way for the Digital Decade" <https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118>

¹³⁸ See: <https://digital-strategy.ec.europa.eu/en/policies/virtual-and-augmented-reality-coalition>

¹³⁹ See: <https://digital-strategy.ec.europa.eu/en/policies/media-and-audiovisual-action-plan>

¹⁴⁰ European Commission, 2023. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 'An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition'. <https://digital-strategy.ec.europa.eu/en/library/eu-initiative-virtual-worlds-head-start-next-technological-transition>

¹⁴¹ Future research and innovation of XR technologies is addressed in: (1) the need for new research infrastructures as set forth in Pillar 1; (2) key XR technologies across all six clusters described in Pillar 2; (3) XR as a base for the innovation ecosystem as presented in Pillar 3. Most of XR technology investments will be concentrated in the Digital, Industry and Space cluster of Pillar 2.

¹⁴² In their focus area of Digital Wellbeing, EIT Digital aims for safeguarding health for the youth, the working professionals and the elderly by analysing sensor data.

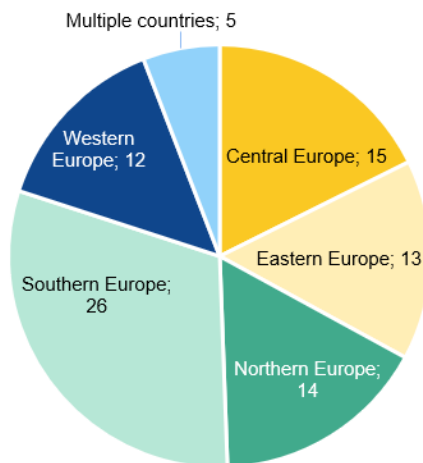
- Material scope of initiatives (e.g., timeline, budget, actors involved, industries, or geographical areas targeted).
- Primary area of intervention (i.e., the type of action).

Lastly, the chapter presents an overview of eight selected flagship public initiatives across all six continents.

3.1. Geographic scope of the initiatives

The database on public initiatives compiled for this study includes 122 entries. Of those, 75 initiatives were implemented in EU Member States, while 45 were implemented in HEAC. Two more initiatives included both EU Member States and HEAC. Out of the total of 122 entries, 11 initiatives had a multi-country focus. No initiatives have been identified for Hungary, Romania, and Georgia during the study period.

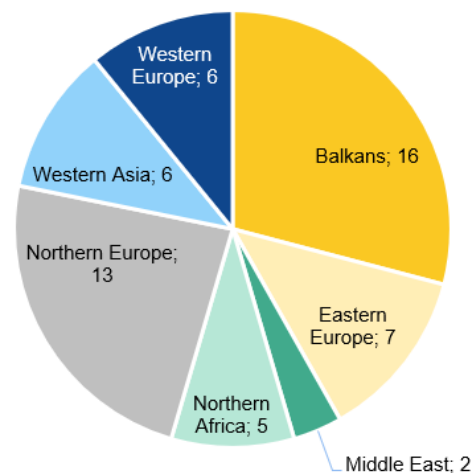
Figure 21. Geographical distribution of the sample of public initiatives in EU Member States



Note: Western Europe comprises Belgium, France, Ireland, Luxembourg, the Netherlands; Central Europe comprises Austria, Czechia, Germany, Hungary, Slovakia; Eastern Europe comprises Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania; Southern Europe comprises Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain; Northern Europe comprises Denmark, Finland, Sweden. Research conducted in November 2022 – April 2023.

Source: Visionary Analytics.

Figure 22. Geographical distribution of the sample of public initiatives in HEAC countries



Note: Balkans comprise Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, Serbia; Northern Europe comprises Faroe Islands, Iceland, Norway; Eastern Europe comprises Moldova, Ukraine; Western Europe comprises United Kingdom; Western Asia comprises Armenia, Georgia, Turkey; Middle East comprises Israel; Northern Africa comprises Tunisia, Morocco. Research conducted in November 2022 – April 2023.

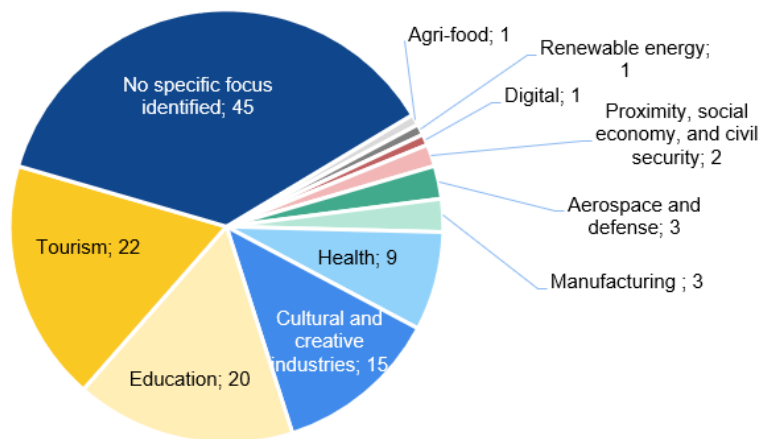
Source: Visionary Analytics.

3.2. Material scope of the initiatives

When examining the geographic area in which the initiatives focus their actions, out of the 122 public initiatives in the database, 28 initiatives were identified as having an area-specific focus (i.e., targeting their activities specifically towards a particular city or municipality area). Additionally, 13 initiatives were identified as having a regional focus within a given country. The majority of initiatives (81) were identified as lacking a strongly pronounced area-specific focus (beyond a general country focus).

For most (77) of the initiatives, it was possible to identify a specific industry focus. Given that this inventory is not a representative sample of public initiatives in Europe and HEAC, this does not reflect the true distribution of public initiatives by the industry they are targeting. However, it can be concluded that examples of public initiatives in tourism, education, and the cultural and creative industries were the easiest to identify through publicly available information.

Figure 23. Distribution of initiatives by industry/sector targeted, number of initiatives



Note: Research conducted in November 2022 – April 2023.

Source: Visionary Analytics.

In terms of actors involved in the implementation of the initiatives, based on the short descriptions available, 41 initiatives also involved some type of industry representatives (companies, associations, etc.), in addition to public action. Furthermore, 52 initiatives involved educational institutions, primarily universities. Among these, 17 initiatives engaged both industry and educational institutions in their implementation.

Information regarding the anticipated funding was unavailable for most of the initiatives (95). However, for the initiatives with available financial information, the funding amounts varied greatly. Eleven initiatives reported funding below €1m, while the remaining 16 activities, for which financial information was available, reported funding over €1m, often surpassing that threshold considerably.

At least some information about the timeline (start and/or end dates) was provided for 103 initiatives. Among these, most initiatives (66) started no later than 2020, while the reported start dates for the remaining 37 initiatives ranged from 1991 to 2019.

3.3. Initiatives by primary area of intervention

To gain insight into the potential impact of the initiatives on the European XR industry and the wider EU internal market, the public initiatives in the dataset were classified according to the primary area of intervention (i.e. type of action of initiative). The following categories were derived using a bottom-up approach (through analysis of individual initiatives and ordering them into broader categories by type of intervention):

- **Adoption of XR/AR/VR solutions** (51 initiatives). Examples include using XR solutions to boost tourism by making cultural heritage accessible to a broader audience, facilitate training (including simulators in aerospace and defence and various educational applications), promote cohesion in local communities (such as through a virtual platform collecting citizens' ideas on local area transformation), and address stress, pain, and mental health-related issues.

- **Access to XR/AR/VR infrastructure** (20 initiatives). These initiatives provide facilities (spaces, tools, laboratories, technology, etc.) for companies, startups, researchers, and individuals to create products, or gain expertise and knowledge in the field.
- **Promotion of XR/AR/VR solutions** (20 initiatives). These initiatives focus on the organisation of various events, such as festivals, workshops, conferences, hackathons, competitions, networks, webinars, and public showcases to raise awareness of existing XR solutions and expand the potential user base.
- **Industry intermediation services** (17 initiatives). These initiatives offer a comprehensive set of services to the industry including knowledge transfer, facilitating fundraising, networking, business mentorship, training, and research. They often provide access to XR infrastructure and organise promotional events.
- **XR/AR/VR-related education, training, and skill development** (eight initiatives). These initiatives concentrate on incorporating XR-related content into ICT educational curricula or providing training themselves, to ensure the development of necessary skills.
- **Research and roadmaps** (six initiatives). These initiatives are dedicated to conducting applied and fundamental research in the field of XR to catalyse the development and deployment of XR technologies.

While none of these public initiatives appear to be ground-breaking or to have a significant impact on the European XR industry as a whole, they can serve as inspiration for addressing key barriers identified in Section 2.4. For instance, initiatives providing access to infrastructure are tackling one of the most important business barriers – technology costs¹⁴³. Similarly, initiatives promoting XR solutions can help overcome societal barriers, such as lack of awareness or user resistance to transitioning from traditional solutions to XR-based solutions¹⁴⁴. Industry intermediation services often have an element of funding (either providing funding or facilitating the search for capital), and business mentorship, tackling financial barriers to the adoption of XR solutions and various business barriers (how to manage costs, user base, market fragmentation, adopt effective business models, etc.), respectively¹⁴⁵. Finally, initiatives integrating XR-related content into education curricula or providing XR-related training help to raise talent with the technical expertise necessary for the installation and operation of XR technologies¹⁴⁶.

The case studies in the following section of this report and Annex 6 provide a more in-depth perspective on how such public initiatives can help businesses, and individuals break barriers and seize opportunities provided by XR and virtual world technologies. The case studies focus on initiatives from various continents and are designed to source insight from outside of EU countries, with the aim to determine whether such initiatives can serve as a good example for addressing challenges that the XR ecosystem is facing in the EU.

¹⁴³ For example, in the education sector, the costs of XR infrastructure are one of the key inhibitors of widespread XR uptake. See Meccawy, M. (2022), 'Creating an Immersive XR Learning Experience: A Roadmap for Educators'. *Electronics* 11, p.3547. <https://doi.org/10.3390/electronics11213547>

¹⁴⁴ A study conducted at the University of Newcastle (Australia) showed that students and staff who had used XR technologies in teaching were more supportive of potential XR investments in their institution. Full reference: Kluge, M. G., Maltby, S., Keynes, A., Nalivaiko, E., Evans, D. J. R., & Walker, F. R. (2022). Current State and General Perceptions of the Use of Extended Reality (XR) Technology at the University of Newcastle: Interviews and Surveys From Staff and Students. *SAGE Open*, 12(2). <https://doi.org/10.1177/21582440221093348>

¹⁴⁵ Some examples of industry intermediation services can be found in the database of public XR initiatives compiled as part of this study, as well as in the case studies outlined in Annex 6 (case studies #1, #3, #5, #6, #7 are relevant to this point).

¹⁴⁶ See Straub, E. T. (2009). 'Understanding Technology Adoption: Theory and Future Directions for Informal Learning'. *Review of Educational Research*, 79(2), 625–649. <https://doi.org/10.3102/0034654308325896> and Reeves, T.C., Lin, L. (2020), 'The research we have is not the research we need'. *Education Tech Research Dev* 68, pp. 1991–2001. <https://doi.org/10.1007/s11423-020-09811-3>

3.4. Deep dive: public initiatives from six continents

This section presents an overview of case studies of the eight selected public initiatives. The selection of these eight public initiatives was based on specific criteria from a total of 48 initiatives (see Annex 1 for more information). See Table 13 for an overview of the initiatives selected for case studies.

Table 13. An overview of the selected case studies and criteria used for selection

#	Continent	Country	Title of the public initiative	Rationale for selection for case studies
1	Europe	United Kingdom	Digital Catapult	Continent: Europe Quality of output: Expected impact - support for businesses in transforming their ideas into valuable products and services Budget: £1.2 billion (overall Catapults funding) Availability of information: Some information publicly available (dedicated website) Example for European initiatives: An example of fostering digital transformation of businesses (one of the pillars of the Digital Compass)
2	Asia	South Korea	Seoul Metaverse	Continent: Asia Quality of output: Unknown Budget: 40.5 billion won (approx. €27.879.500,00) - estimate Availability of information: Initiative has gained a lot of traction and there is a lot of information available about it. Example for European initiatives: Example of digitalisation of public services (one of the pillars of the Digital Compass)
3	North America	US	RLab	Continent: North America Quality of output: Unknown Budget: \$5.6 million Availability of information: Some information publicly available (one website dedicated to initiative and 6 additional articles) Example for European initiatives: Example of an initiative in the area of digital transformation of businesses (one of the pillars of the Digital Compass)
4	Asia	UAE	Metaverse customer happiness service centre (Metahealth)	Continent: Asia Quality of output: "The UAE wise leadership is keen to keep pace with and explore future changes and transformations to actively contribute to shaping and making them, as an important priority and a key pillar of future government services," said HE Abdul Rahman bin Muhammad Al Owais, Minister of Health and Prevention. "The UAE has been a pioneer in accelerating innovation in all vital sectors, including health, while the ministry of health was one of the leading and active authorities in the Fourth Industrial Revolution technologies, which focus on artificial intelligence, blockchain, virtual and augmented reality." Budget: Unknown fraction of AED 53.7m (approx. €13.6m) Availability of information: Initiative has gained a lot of traction and there is a lot of information available about it Example for European initiatives: Example of digitalisation of public services (one of the pillars of the Digital Compass)
5	Australia and Oceania	Australia	Queensland XR hub	Continent: Australia and Oceania Quality of output: Unknown Budget: Unknown Availability of information: Some information publicly available. Example for European initiatives: Activities include assisting local industry, corporate and government organisations to better understand and engage with

#	Continent	Country	Title of the public initiative	Rationale for selection for case studies
				Immersive Technologies through education and events (digital skills, digital transformation of businesses, corresponding to two pillars of the Digital Compass)
6	South America	Argentina	19 units of digital transformation	Continent: South America Quality of output: unknown Budget: 88.045.431 ARS (approx. €352,000.00) Availability of information: Some information publicly available. Example for European initiatives: Example of an initiative in the area of digital transformation of businesses (one of the pillars of the Digital Compass), however, it seems that this initiative touches upon XR only through seminars (which is a small part of the initiative)
7	Africa	South Africa	Electric South	Continent: Africa Quality of output: Unknown Budget: Approx. €27.500 in public funding (overall budget unknown) Availability of information: Some information publicly available. Example for European initiatives: Digital transformation of businesses in the arts sector
8	South America	Brasil	RAEscolas	Continent: South America Quality of output: Unknown Budget: Unknown Availability of information: Some information publicly available. Example for European initiatives: Example of an initiative in the area of digital skills (one of the pillars of the Digital Compass)

Source: compiled by Visionary Analytics.

The full text of the case studies is available in Annex 6 of this report. For more details on the methodology of the case studies see Annex 1. Below we present insights stemming from the cross-case analysis.

In terms of the **context of the initiatives**, most of the initiatives included in the case studies are part of broader digital policy frameworks, most commonly frameworks for the digitalisation of industry or innovation in general (Argentina, Australia, UK). The Metahealth and Seoul Metaverse initiatives are part of frameworks for the transformation of public services. Interestingly, the RLab initiative was part of an overarching policy plan aimed specifically at generating well-paying technology jobs, showcasing an example of using an XR-related initiative as a vehicle to drive labour market changes. RAEscolas and Electric South initiatives seem to be stand-alone actions and not explicitly part of any broader policy frameworks.

The **actions and outputs** of the analysed initiatives fall broadly into three categories:

- Creation of the *metaverse* to facilitate the provision of public services to citizens (Metahealth and Seoul Metaverse).
- *Comprehensive programmes/institutions* providing physical facilities, access to know-how, resources, and technology, often operating in a defined region/locality (RLab in New York, activities of Digital Catapult in different regions of the UK, Queensland XR Hub), or focusing on a particular sector (Electric South focusing on the film industry).

- *Creation of XR-based solutions and applications* (RAEscaras with the creation of educational artefacts, and the 19 units of digital transformation in Argentina with the foreseen repository for digital solutions and tools for enterprises).

Alongside the public institutions responsible for the initiative, other **actors** were also involved in the implementation and operation of the initiative, namely various industry actors and private companies, universities, chambers of commerce, associations, foundations, and non-profits.

Most of the initiatives studied under the case studies were **launched**, announced, or started operations in 2022, whereas the Digital Catapult, Electric South, and RLab started operations in 2013, 2015, and 2019, respectively. The Queensland XR Hub is operational, as of 2020.

Information about the **funding** of the initiatives was scarce in most cases, often referring to broader envelopes of funding (which include the initiative in the focus of the case study). However, the initiatives amassed significant amounts of funding, in most cases counting in millions of USD.

Overall, the case studies offered insight into possible ways of addressing **key barriers** to the adoption of XR in Europe. In terms of *technological barriers*:

- The Metahealth initiative tackled the issue of lack and inadequateness of existing software for XR applications, by commissioning the development of an *ad-hoc* software solution.
- The facilities provided by RLab and Digital Catapult make technology that is often expensive (such as visors or simulators) available to smaller businesses, mitigating the risk connected to investment in hardware.

In terms of *business barriers*:

- Digital Catapult serves as an industry intermediary, helping large businesses identify opportunities to monetise XR solutions by focusing on the importance of change management and piloting of solutions, especially when ambitious plans for the adoption of XR are introduced.
- RAEscaras and Metahealth are providing easy access to their products (via an app or web browser), without the need for users to have specialized hardware, cutting costs for consumers.
- The Argentinian initiative of the 19 units of digital transformation exemplifies how to 'start small', and exploit the spaces and expertise already available in other institutions without the need to build laboratories and facilities to enable knowledge transfer.
- Seoul Metaverse is an example of how access to services in a virtual environment can eventually help industries widen their audience by generating more demand for virtual solutions.

In terms of *financial barriers*:

- Member-based XR Hubs, such as the Queensland XR Hub, combine funding and mentorship, including improvement and/or establishment of strong business plans, with the aim to attract investments for XR industries. An example of success is the sizeable investment made by Boeing in a Queensland XR startup, facilitated through the operations of the Queensland XR Hub.

- Similarly, initiatives, such as RLab's partnership with CUNY's Macaulay Honors College provide improved access to resources for the study and development of innovative XR solutions.

In terms of *societal barriers*:

- The two metaverse initiatives from the UAE and South Korea are tied to the provision of highly important public services. These platforms aim to significantly improve the quality of life for the public and are easy to use. Part of their success will be assessed by their effective capacity to boost public confidence in, and attitudes towards, virtual technologies. Moreover, these platforms aim for a very wide user base. If successful, they will be in a position to help address the challenge of a small user base for XR technologies.
- The community engagement component (events, workshops, etc.) of initiatives, such as RLab and Electric South, is designed to help boost user awareness of XR technologies and increase their confidence in them.

The case studies also provide some inspiration for how such public initiatives could contribute to fostering the adoption of XR in the **key industrial ecosystems** in Europe. The list below is not aimed to be exhaustive, but is rather aimed at showcasing some of the possibilities on how to address some of the barriers specific to the industrial ecosystems:

- *Aerospace and defence, digital, and electronics* ecosystems could benefit from a comprehensive programme (combining funding, mentorship, and physical facilities, as exemplified by the RLab, Digital Catapult, and Queensland XR Hub), to foster a more integrated European XR market to tackle the outside competition that today weakens the EU XR market in these ecosystems¹⁴⁷. Access to funding related to content development is a particularly salient barrier for the *cultural and creative industries, and proximity, social economy, and civil security* ecosystems¹⁴⁸.
- *Agri-food* ecosystem could benefit from mentorship opportunities (as exemplified by the RLab, Digital Catapult and Queensland XR Hub), to identify more effective business models for XR applications¹⁴⁹.
- *Construction and energy-intensive industries* ecosystems have been identified as ones that are adopting XR as a productivity solution relatively sparingly, however, there are already clear XR use cases showcasing increased productivity and efficiency¹⁵⁰. Events and workshops, like those organised by the 19 units of digital transformation in Argentina, could be examples of how to promote XR technologies.
- The work of Digital Catapult and Electric South provides inspiration on pooling resources, providing funding, harnessing talent, and providing other intermediation services to the entire *cultural and creative industries* ecosystem¹⁵¹.
- The Metahealth initiative is a great example of how to capitalize on key opportunities provided by virtualisation technologies (in particular, increasing the sustainability of

¹⁴⁷ See Table 9.

¹⁴⁸ See Table 10.

¹⁴⁹ See Section 0 of this report.

¹⁵⁰ Rokooei, S., Javan, B., & Nazari, A. (2022). Explore Challenges and Benefits of Virtual Reality in Construction Projects. Proceedings of the Creative Construction E-Conference 2022. <https://doi.org/10.3311/ccc2022-037>

Knoke, B., Quandt, M., Freitag, M., & Thoben, K. (2021). Virtual Reality Training Applications in Industry - Towards a User-friendly Application Design. Goto Verlag EBooks, 59–80. https://doi.org/10.30844/wgab_2021_4

¹⁵¹ Please see case studies #1 and #7 outlined in Annex 6.

the ecosystem, by reducing travel and physical lines at healthcare centres)¹⁵² for the *health* ecosystem.

- Strong community engagement through designated collaborative projects (such as the RLab) could foster increased public awareness of (and confidence in) XR, which would help ecosystems that perceive this to be a big barrier to XR adoption, namely *agri-food, energy-intensive industries, energy renewables, retail, textile and fashion, and tourism*¹⁵³.
- *Retail*¹⁵⁴ and *tourism*¹⁵⁵ ecosystems stand to gain a lot from various virtual worlds initiatives, as they would be able to create ad-hoc products to use in the virtual worlds, such as virtual outfits and virtual tours.

¹⁵² Interviews with SyncVR, Sint Maartens, EIT Health; European Commission, Directorate-General for Communications Networks, Content and Technology, Visionary Analytics, IDEA Consult, Boel, C., Dekeyser, K., Depaepe, F., et al., Extended reality: opportunities, success stories and challenges (health, education): final report, Publications Office of the European Union, 2023. Available [here](#).

¹⁵³ See Table 11.

¹⁵⁴ Hassounah D. and Brengman, M. (2015), 'Retailing in social virtual worlds: Developing a typology of virtual store atmospherics'. *Journal of Electronic Commerce Research* 16(3), pp.218-241.

¹⁵⁵ Trunfio, M., Della Lucia, M., Campana, S., & Magnelli, A. (2021). 'Innovating the cultural heritage museum service model through virtual reality and augmented reality: the effects on the overall visitor experience and satisfaction'. *Journal of Heritage Tourism*, 17(1), 1–19. <https://doi.org/10.1080/1743873x.2020.1850742>

4. Emerging technologies and their potential impact on XR and virtual worlds

Emerging technologies have always been instrumental in XR development, with a significant influence on the user experience. In addition, XR technologies plays an important role in enabling technology for virtual worlds.¹⁵⁶ The following section presents relevant emerging technologies and their potential for both XR and virtual worlds.

Emerging technologies are innovations that are thought to have the potential to significantly impact industry and society. Based on desk research, consultations with experts from different technological areas, and Delphi survey findings, the following emerging technologies were identified as relevant to the field of XR: novel photonic technologies for display, optics and sensing (including haptic solutions), connectivity (5G and 6G, and Wi-Fi 6/7), edge computing (edge-offloading), cloud computing (AR/VR cloud, hybrid cloud), advanced semiconductor chips (devices, efficiencies, and capabilities), graphene and metamaterials, blockchain, and artificial intelligence (AI). The potential of each of the emerging technologies on XR and virtual worlds is presented below, including a discussion on how they can help overcome the current challenges of XR adoption¹⁵⁷.

The technologies are also interrelated. Software solutions are limited by hardware, and there remains room for developing software to better utilise hardware capabilities. Desk research and respondent feedback supports the finding that for successful and efficient development and uptake of XR, interoperability of these technologies is essential, and it is necessary to invest in cross-platform connections to facilitate unlocking the full potential of emerging technologies. To briefly illustrate, emerging technologies, such as edge and cloud computing, will rely on robust connectivity (5G and 6G, and Wi-Fi 6/7), and connectivity can also be facilitated by metamaterials; metamaterials are set to overtake traditional materials in advanced semiconductors;¹⁵⁸ advanced semiconductor chips can also improve wearable devices, displays, and optics, areas which will benefit greatly from advances in metamaterial technology, and which also rely on efficient connectivity and cloud processing solutions; blockchain too complements these technologies by offering security and privacy solutions and has the potential to be integrated with cloud and edge computing.

4.1. Novel photonic technologies for displays

4.1.1. Potential on XR and virtual worlds

Headsets used in XR rely on novel photonic technologies for high-quality image display. Graphical display systems, which display information, images, or data to a user, aim to address human visual depth cues with the best possible resolution, colour accuracy, and brightness, with minimum weight and at the lowest possible costs.¹⁵⁹ Quality image generation and display create the optimum XR immersive experience. The virtual worlds concept also implies seamless 3D workspaces, and these require high-quality, realistic, ergonomic VR and AR experiences. The vision of seamlessness means that users may switch to any other VR or AR device according to their actual needs, but retain access to the same 3D data. **Novel photonic technologies could change the way virtual reality is experienced**, and experts in the Delphi survey indicated its importance for XR, with half of experts objecting (50% or eight out of 16) to the idea that novel photonic technologies

¹⁵⁶ Lik-Hang Lee et al., *All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda*, 2021, <https://doi.org/10.13140/RG.2.2.11200.05124/8>.

¹⁵⁷ These descriptions were prepared by the project team experts with knowledge about each of the technology, and relies on their expertise, if no specific reference is provided.

¹⁵⁸ Hedges, P., 2022. The industrialization of graphene. Mark Allen Group. Available at: <https://www.newelectronics.co.uk/content/features/the-industrialisation-of-graphene/>.

¹⁵⁹ Kemeny, A., Chardonnet, J. R., & Colombet, F. 2020. Getting rid of cybersickness. *Virtual Reality, Augmented Reality, and Simulators*. Springer Cham. <https://doi.org/10.1007/978-3-030-59342-1>.

are less important for the development of the application of XR (including virtual worlds) than other emerging technology fields. However, some experts in the Delphi survey expressed concern about the speed of technology development.

VR headsets are usually based on LCD and on OLED technology. The vast majority of recently released VR headsets (vrgineers XTAL,¹⁶⁰ Meta Quest Pro,¹⁶¹ Pico 4,¹⁶² HTC XR Elite¹⁶³) use LCD instead of OLED or AMOLED displays within their VR headsets. The latest see-through AR smart glasses work on a LASER MEMS basis (Apple) or on OLED on Silicon-Panele (OLEDoS) with an very high resolution (3,500PPI).¹⁶⁴ ¹⁶⁵ OLEDoS will be particularly relevant for micro-displays for AR and VR devices, and, instead of using glass as a substrate, which is more traditional, they use silicon.¹⁶⁶ According to sources¹⁶⁷, Samsung Display is also working on LEDoS displays, which should offer a lower entry hurdle than OLEDoS, but has very high display resolutions (6,600 PPI).

4.1.2. Overcoming current challenges of XR adoption

One challenge related to use of headsets can be **cybersickness**. Displays or projections are usually designed as single-user VR system because the correct perspective view is calculated on the basis of one head-tracked person. Due to this, in many huge VR installations head tracking is switched off to avoid cybersickness to the non-tracked persons, but this can limit the immersiveness of the experience. The countermeasure to this is to provide not only one perspective (left eye view and right eye view for one observer), but to provide individual perspective views to all observers and to head-track all observers. The image separation between the users and between their left eyes and right eyes can be done by stereo separation mechanisms. However, only a few manufacturers have brought products on the market that utilise these mechanisms.¹⁶⁸ In addition, **advancing photonic technologies for display can contribute to the challenges of providing correct perspectives in XR**, while avoiding the common problem of cybersickness, which can limit the update of XR applications.

4.2. Optics and sensing (including haptic solutions)

4.2.1. Potential on XR and virtual worlds

Although during the first round of the Delphi survey some experts suggested that optics and sensing are less important for the development of XR applications than other emerging technology fields, during the second round of the Delphi survey, 75% (12 out of 16) of respondents disagreed or strongly disagreed with this finding. **Innovations in optics** (such as lens technologies) **are integral to the advancement of functional and lightweight devices**, which allow for a fully immersive visual experience, as echoed by many of Delphi survey respondent comments.

¹⁶⁰ See: <https://vrgineers.com/xtal-3-mixed-reality/>; <https://vrgineers.com/xtal-3-virtual-reality/>; <https://vrgineers.com/xtal/>

¹⁶¹ See: <https://forwork.meta.com/gb/quest/quest-pro>

¹⁶² See: <https://www.picoxr.com/uk/products/pico4>

¹⁶³ See: <https://www.vive.com/uk/product/vive-xr-elite/overview/>

¹⁶⁴ Davis, G. 2022. Apple Glasses to Have Enhanced OLED Microdisplay Density; Is 3500 PPI Really Possible? Tech Times. Available at: <https://www.techtimes.com/articles/281256/20220930/apple-glasses-enhanced-oled-microdisplay-density-3500-ppi-really-possible.htm>.

¹⁶⁵ See: Kress, B. C., & Pace, M. 2022. Holographic optics in planar optical systems for next generation small form factor mixed reality headsets. Light: Advanced Manufacturing 3, 55. doi: 10.37188/lam.2022.042

¹⁶⁶ Yoon, Y. 2022. OLEDoS: Technological Breakthrough for AR/VR Devices. Counterpoint. Available at: <https://www.counterpointresearch.com/insights/oledos-technological-breakthrough-xr-devices/>

¹⁶⁷ Lee, G. 2022. Apple request development of 3500ppi OLEDoS to Samsung and LG. TheElec. Available at: <https://www.thelec.net/news/articleView.html?idxno=4220>.

¹⁶⁸ Available products include: BARCO's "Dual Eye Point" feature which allows to display two independent 3D stereo images on the same screen with one high frame-rate projector (<https://www.barco.com/de/product/dual-eye-point>); Digital Projection's "NSIGHT 4K HFR 360" allows for three individual views (<https://www.digitalprojection.com/en/digital-projection-insight-4k-hfr-360-brings-multiview-3d-to-the-industry-in-4k/>); The start-up xCave Technology now offers a dual perspective VR powerwall or CAVE solution based on LED panel tiles (: <https://www.xcave-technology.de/System>).

Advances in optics and sensing may enable more robust hardware with better field-of-view and multimodal stimulation of senses for more engaging XR experiences. For example, first trials have been undertaken using contact lenses as smart glasses; start-up company “*Mojo Vision*” showed the first prototypes of its smart contact lens, which included an Amazon Alexa integration for shopping.¹⁶⁹ Moreover, lens optics technologies have evolved (and continue to do so), from traditional Fresnel lenses to aspheric and most recently, to pancake design lenses.¹⁷⁰ The development of new optics technologies can be applied in XR devices to improve user experience and remove barriers to entry (such as cybersickness¹⁷¹).

Sensing technology is vital for generating realistic virtual environments. Tracking technology in particular is an important component, which generates a seamless XR experience to effectively mimic movement and translate this into a 3D virtual environment (as with real-time digital twins)¹⁷². Moreover, there are a vast array of 3D data sources that are now used to transfer 3D content to XR, e.g., design data, BIM models, medical CT, and MRT data, 3D city models, and so on. Any algorithm and application that will help to automate the production of relevant 3D content from legacy IT systems will have an extremely high economic potential.

Haptics also contribute to the experience of XR by providing users with physical feedback from the virtual environment, making XR experiences more seamless and functional. The topics of prosthesis technology, work-supporting exoskeletons, and VR haptics are increasingly technologically related,¹⁷³ and the advancements in these technologies stand to benefit from each other. Therefore, big potential for innovation in optics and sensing is also predicted for the MedTech sector. While sensing and haptics have important potential applications, almost all of the experts in the second round of the Delphi survey strongly agreed or agreed (94% or 15 out of 16) that the use of suits, gloves, and scents to complement the experiences needs improvement and more accessible costs.

The combination of optics and sensing technologies (including haptic solutions) can enable fast and responsive devices, lightweight devices, excellent quality images, and realistic haptic output. These contribute to creating devices, which are responsive to the environment, making it easier to navigate. A more seamlessly generated XR and virtual worlds experience is key to drive wider uptake of the technologies.

4.2.2. Overcoming current challenges of XR adoption

Optics influence the immersive experience of an XR or virtual worlds’ user, thus developments in optic technologies can overcome some of the issues currently faced by users. Negative optic effects experienced by users can include God Rays, Rainbow effects, or headaches, due to the vergence-accommodation issue (difficulties with users adjusting focus and alignment while viewing display technologies)¹⁷⁴. Currently, the vast majority of VR headsets use relatively inexpensive Fresnel lenses to magnify images and bring them into focus. While more affordable and lightweight, these designs produce a number of

¹⁶⁹ BusinessWire. 2022. Mojo Vision Announces Test Integration With Alexa Shopping List on Smart Contact Lens.

Available at: <https://www.businesswire.com/news/home/20221103005395/en/Mojo-Vision-Announces-Test-Integration-With-Alexa-Shopping-List-on-Smart-Contact-Lens>

¹⁷⁰ Ren, Z., Fu, X., Dong, K., Lai, Y., & Zhang, J. 2023, May. Advanced Study of Optical Imaging Systems for Virtual Reality Head-Mounted Displays. *Photonics*, 10 (5). <https://doi.org/10.3390/photonics10050555>.

¹⁷¹ Kemeny, A., Chardonnet, J. R., & Colombet, F. 2020. Getting rid of cybersickness. *Virtual Reality, Augmented Reality, and Simulators*. Springer Cham. <https://doi.org/10.1007/978-3-030-59342-1>.

¹⁷² Syed, T.A., Siddiqui, M.S., Abdullah, H.B., Jan, S., Namoun, A., Alzahrani, A., Nadeem, A. and Alkhodre, A.B., 2022. In-depth review of augmented reality: Tracking technologies, development tools, AR displays, collaborative AR, and security concerns. *Sensors*, 23(1), p.146.

¹⁷³ See: Giri, G.S., Maddahi, Y. & Zareinia, K., 2021. An application-based review of haptics technology. *Robotics*, 10(1), p.29.

¹⁷⁴ IDTechEx, 2022. Optics for Virtual, Augmented and Mixed Reality 2022-2032: Technologies, Players and Markets. Available at: <https://www.idtechex.com/en/research-report/optics-for-virtual-augmented-and-mixed-reality-2022-2032-technologies-players-and-markets/870>

optical artifacts that compromise the quality and comfort of the virtual experience. Newer optical technologies promise to solve many of these issues, while adding functionality for a more immersive experience and making headsets smaller. For example, innovative optical components based on “birdbath” lenses (a lens with a convex surface), holographic, and dynamic focus tuning effects are expected to upgrade lenses in XR headset designs over the coming decade.¹⁷⁵

4.3. Connectivity (5G and 6G, Wi-Fi 6/7)

4.3.1. Potential on XR and virtual worlds

XR applications rely on **stable and low-latency wireless networks**, which can provide higher bandwidth and enable real-time communication. One of the key features of the 5G network is that it enables Wide Area Extended Reality (WAXR) applications and new XR (and virtual worlds) use cases. For example, Enhanced Mobile Broadband (eMBB) allows the network to exchange a large amount of data at high-speed to enable applications, such as immersive gaming.¹⁷⁶ Massive Machine Type Communications (mMTC) applications enable the connection of a large number of devices, such as smart cities and self-driving cars.¹⁷⁷ Finally, Ultra Reliable Low-Latency Communications (URLLC) are so-called critical applications that require a high level of network reliability, such as telemedicine and AR/VR.¹⁷⁸

Both wide access (5G and 6G) and local access (Wi-Fi 6/6E and Wi-Fi 7) network connectivity are crucial to XR, particularly as XR applications continue to develop, requiring advanced capabilities.¹⁷⁹ Connectivity is also a key component for virtual worlds¹⁸⁰ and users want to connect easily, without cables, lag, or friction. Firstly, further improvements brought by next-generation Wi-Fi (Wi-Fi 6/6E and Wi-Fi 7) will undeniably render XR experiences within virtual worlds in the future (i.e. in local area XR (LAXR) application).¹⁸¹ Wi-Fi 6/6E and later Wi-Fi 7 infrastructure will provide XR users in home and business environments with **high-performance connectivity within localised spaces** and will allow to build connections between the physical and digital worlds. Secondly, 6G will investigate novel communication modes without regard for existing network paradigms or technology,¹⁸² providing reliable and robust connectivity, and access to wide area XR (WAXR), which can better support the requirements of XR applications.¹⁸³ The completion of the 6G standard and its commercialisation is anticipated as early as 2028.¹⁸⁴ Moreover, 5G and 6G infrastructure will provide bandwidths, which are better capable of handling

¹⁷⁵ Optics. 2022. Report: emerging optics to displace Fresnel lenses in XR headsets. Available at: <https://optics.org/news/13/6/8>.

¹⁷⁶ Milovanovic, D., Bojkovic, Z., & Pantovic, V. 2019. Evolution of 5G mobile broadband technology and multimedia services framework. In Smart and Sustainable Engineering for Next Generation Applications: Proceeding of the Second International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering (ELECOM 2018), November 28–30, 2018, Mauritius 2 (pp. 351-361). Springer International Publishing.

¹⁷⁷ Shehab, M. J., Kassem, I., Kutty, A. A., Kucukvar, M., Onat, N., & Khattab, T. (2021). 5G networks towards smart and sustainable cities: A review of recent developments, applications and future perspectives. *IEEE Access*, 10, 2987-3006.

¹⁷⁸ Feng, D., Lai, L., Luo, J., Zhong, Y., Zheng, C., & Ying, K. 2021. Ultra-reliable and low-latency communications: applications, opportunities and challenges. *Science China Information Sciences*, 64, 1-12.

¹⁷⁹ Akyildiz, I.F. and Guo, H., 2022. Wireless communication research challenges for extended reality (XR). *ITU Journal on Future and Evolving Technologies*, 3(1), pp.1-15.

¹⁸⁰ The survey questionnaire used term metaverse, but the report was revised to be in line with the vocabulary used in Communication adopted by the European Commission on 11 July 2023, setting out a strategy focusing on Web 4.0 and virtual worlds.

¹⁸¹ Elliott, I., 2022. When Will Wi-Fi Really Support the Metaverse? Light Reading. Available at: <https://www.lightreading.com/when-will-wi-fi-really-support-metaverse-/a/d-id/776348>.

¹⁸² Lu, Y. and Zheng, X., 2020. 6G: A survey on technologies, scenarios, challenges, and the related issues. *Journal of Industrial Information Integration*, 19, p.100158.

¹⁸³ Bariah, L., Mohjazi, L., Muhaidat, S., Sofotasios, P.C., Kurt, G.K., Yanikomeroğlu, H. and Dobre, O.A., 2020. A prospective look: Key enabling technologies, applications and open research topics in 6G networks. *IEEE access*, 8, pp.174792-174820.

¹⁸⁴ Bojkovic, Z., Milovanovic, D., Fowdur, T.P. and Indoonundon, M., 2021. 6G ultra-low latency communication in future mobile XR applications. In *Advances in Signal Processing and Intelligent Recognition Systems: 6th International Symposium, SIRS 2020, Chennai, India, October 14–17, 2020, Revised Selected Papers 6* (pp. 302-312). Springer Singapore

remote rendering services, such as small, wearable devices, with less energy consumption (as larger computational efforts, such as rendering, are outsourced to a computing centre). It is also thought that 5G and 6G will enable new mobile AR assistance applications, based on both AR vision and audio,¹⁸⁵ such as the acoustic glasses Echo Frames (Amazon) and Focal (North).

4.3.2. Overcoming current challenges of XR adoption

Currently, existing Wi-Fi performance is insufficient for the developing class of rich (highly interactive, immersive, and resource-intensive) apps that will be part of XR and virtual worlds. The ability to utilise the latest **Wi-Fi technologies will be a prerequisite for the next generation of XR devices, allowing for reliable and responsive experiences.** Support for the latest Wi-Fi technologies will also be a necessity for providers of routers and access point devices too, enabling users to access XR technologies to the maximum potential on their own, local network. Moreover, XR applications require the full capacity of 5G standalone (SA), but current 5G networks and Wi-Fi cannot meet the ideal requirements for XR experiences.¹⁸⁶ 6G will act as the solution to the limitations of current 5G technology.

4.4. Cloud computing (AR/VR cloud, hybrid cloud)

4.4.1. Potential on XR and virtual worlds

Developers commonly use cloud-based systems for collaborative work and storage. Cloud-based solutions can allow **location-independent connections**, which make it easier for developers to create and manage XR (and virtual worlds) applications, and XR developers and users will continue to rely heavily on cloud computing. Additionally, cloud-based systems can be **customised and configured** to meet the specific needs of XR (and virtual worlds), such as specialised processing hardware.¹⁸⁷

Moreover, using cloud technology is essential when dealing with large-scale data. In particular, the dimensions of virtual worlds, when fully developed, will create massive demands for storage and processing power that can only be met by massively scalable solutions. Cloud-based systems can be easily scaled to meet the demands of XR (and virtual worlds),¹⁸⁸ meaning that **software solutions can be scaled to the demand of the market.** This was supported by responses from the Delphi survey, where cloud computing was rated as important or very important for the development of XR applications (including virtual worlds) by 92% (41 out of 51) surveyed experts. Most importantly scalability, but also the flexibility of hardware configuration towards specific workloads, are crucial advantages of cloud technology for virtual worlds' development and are needed to make very advanced applications possible, e.g., AI or real-time rendering. Cloud computing means that the growing XR and virtual worlds' user base and ever-changing software products are not as limited by, for example, storage and computation capabilities.

4.4.2. Overcoming current challenges of XR adoption

Computational offloading and storage facilitated by the cloud also **lower the costs** of a fully immersive experience by removing the need for high-end XR devices at the local level. Instead, cheaper devices that offer a longer lifespan can be incorporated. The cloud acts

¹⁸⁵ Taleb, T., Nadir, Z., Flinck, H., & Song, J. 2021. Extremely interactive and low-latency services in 5G and beyond mobile systems. *IEEE Communications Standards Magazine*, 5(2), 114-119.

¹⁸⁶ Akyildiz, I.F. and Guo, H., 2022. Wireless communication research challenges for extended reality (XR). *ITU Journal on Future and Evolving Technologies*, 3(1), pp.1-15.

¹⁸⁷ Google Cloud. 2023. Custom Machine Types. Available at: <https://cloud.google.com/custom-machine-types>

¹⁸⁸ Theodoropoulos, T., Makris, A., Boudi, A., Taleb, T., Herzog, U., Rosa, L., Cordeiro, L., Tserpes, K., Spatafora, E., Romussi, A. & Zschau, E., 2022. Cloud-based XR services: A survey on relevant challenges and enabling technologies. *Journal of Networking and Network Applications*, 2(1), pp.1-22.

as an anchor, which can be shared and accessed by multiple users across a range of devices and allows for **greater XR collaboration and engagement**. In addition, storing data and processing workloads in the cloud is a feasible solution to **facilitate virtual worlds' experience that is not limited by barriers, such as service outages or queues** because of limited storage or processing power. With the use of the cloud, XR becomes more accessible as users can use more affordable devices, move around more freely.

Having said this, as cloud computing relies on sending and receiving data across potentially large distances to external servers, there can be problems with latency and connection losses, especially when the connectivity infrastructure is not reliable.¹⁸⁹ Edge computing offers an alternative to cloud computing, which mitigates these challenges, as discussed below.

4.5. Edge computing (edge-offloading)

4.5.1. Potential on XR and virtual worlds

In the context of XR, edge computing, or 'offloading', shifts the heavy lifting of intensive data processing and storage to more capable and specialised computing devices, such as servers (this is also known as a thin-client approach). Not only does this **reduce the cost of Human Interface Devices (HIDs), but it also extends the lifespan of the device**,¹⁹⁰ as computing hardware can evolve separately from the interface device. In addition, mobile edge networks are expected to deliver **low-latency and wide-area wireless access, enabling a fully immersive and real-time user experience in virtual worlds**.¹⁹¹ The improved latency that comes from edge computing (when supported by appropriate connectivity infrastructure) facilitates real-time or near real-time processing, which is integral to XR and virtual worlds' applications.

Moreover, edge computing brings additional **flexibility and competition into the XR industry**, by enabling software as a service (SaaS) like business models by disaggregating and unbundling the XR-value chain. However, currently, there is a **lack of standardisation** in the field of edge computing, which makes it difficult for developers to create and implement consistent and compatible systems. To experience a seamless virtual world with applications being compatible, global standards must be created and widely adopted. When those standards are met, developers have the safety to create applications that can make use of edge offloading globally.¹⁹²

4.5.2. Overcoming current challenges of XR adoption

Edge-based systems can overcome the latency issues associated with cloud computing (described above), which have a negative impact on virtual worlds' and XR user experience. At most geographical locations, the traffic computed in the cloud must travel distances that become noticeable to the user as latency. This, however, is tackled by the concept of edge computing, which has the **potential to reduce latency to a sufficient minimum**.¹⁹³

¹⁸⁹ Akyildiz, I.F. and Guo, H., 2022. Wireless communication research challenges for extended reality (XR). *ITU Journal on Future and Evolving Technologies*, 3(1), pp.1-15.

¹⁹⁰ Hassan, N., Gillani, S., Ahmed, E., Yaqoob, I., & Imran, M. (2018). The role of edge computing in internet of things. *IEEE communications magazine*, 56(11), 110-115.

¹⁹¹ Xu, M., Ng, W.C., Lim, W.Y.B., Kang, J., Xiong, Z., Niyato, D., Yang, Q., Shen, X.S. and Miao, C., 2022. A full dive into realizing the edge-enabled metaverse: Visions, enabling technologies, and challenges. *IEEE Communications Surveys & Tutorials*. Available at: https://www.researchgate.net/publication/359156157_A_Full_Dive_into_Realizing_the_Edge-enabled_Metaverse_Visions_Enabling_Technologiesand_Challenges.

¹⁹² ETSI (European Telecommunications Standards Institute) has already made efforts to harmonize standards for edge computing. See: ETSI. 2020. Harmonizing standards for edge computing – A synergized architecture leveraging ETSI ISG MEC and 3GPP specifications. Available at: https://www.etsi.org/images/files/ETSIWhitePapers/ETSI_wp36_Harmonizing-standards-for-edge-computing.pdf.

¹⁹³ Hassan, N., Gillani, S., Ahmed, E., Yaqoob, I., & Imran, M. (2018). The role of edge computing in internet of things. *IEEE communications magazine*, 56(11), 110-115.

In order to increase the adoption of large-scale, especially mass-market consumer-grade XR use cases, technical limitations need to be solved. One of the most pressing issues is the physical hardware required to run high-quality XR applications. Currently, there is still the need to perform most of the computation on-device, which either leads to bulky untethered devices, or lighter, but tethered, HIDs. However, in combination with advanced connectivity standards, like 5G, 6G, or Wi-Fi 6/7, XR hardware can benefit from using edge computing through its **capabilities to handle the required bandwidths for computation offloading**, and, as a result, the comfort and handling of the hardware are improved.¹⁹⁴

The demands for low-latency, data protection, and security are the most important challenges for applications that rely on the cloud for a safe and convenient XR user experience. Technological advances, such as widely available edge computing for latency, and high-security standards for data protection, should take place to meet those challenges.

4.6. Advanced semiconductor chips (devices, efficiencies, capabilities)

4.6.1. Potential on XR and virtual worlds

The next generation of XR devices will be supported by advanced chip technology. As an example, a notable leader in the field is the American semiconductor company Qualcomm. In 2022, Qualcomm announced the opening of its XR Labs in Europe,¹⁹⁵ with a focus on research and development, and providing access to innovative XR technology to a range of sectors.

As with other modern smart devices, XR headsets and glasses also feature innovative **system-on-a-chip (SoC) technology**.¹⁹⁶ Semiconductor chip development is the key to producing user-friendly hardware. Moreover, due to their proliferation, smartphones (enabled by ever-more advanced chip technology) will continue to act as an important XR entry point, supporting the adoption of XR by making the technology more accessible to a greater number of people.¹⁹⁷ While advanced chip technologies in smartphones should enable such devices to continue to act as a gateway to some XR applications, dedicated XR processor platforms should also serve to benefit the development of new XR devices.

System-on-a-chip innovation within the smartphone industry will also be applied to other mobile device markets, notably the advanced integration of components, such as a high-performance processor, graphics, and AI accelerator chips specifically designed to manage AI processed data¹⁹⁸ on a single silicon-based chip that is capable of supporting the **next generation of power-efficient, lightweight XR devices**, which deliver enhanced visuals, sound, and immersive experiences while preserving battery life.

Industry collaboration has the potential to bring together key components, so that a single chip manufacturer could develop standalone devices with all the capabilities required to deliver truly immersive experiences, including those within virtual worlds. For example, Qualcomm's activity within the XR space includes **partnerships with other tech firms**, particularly those who are also actively exploring XR applications and virtual worlds. A

¹⁹⁴ The use of thin client at scale has already been demonstrated in industry. See: Verizon. 2023. What is the AR cloud and what is it used for? Available at: <https://www.verizon.com/about/blog/what-is-ar-cloud>.

¹⁹⁵ Qualcomm. 2022. Qualcomm Expands Investment in XR and the Metaverse with the Formation of XR Labs Europe – an XR R&D hub in Europe. Available at: <https://www.qualcomm.com/news/releases/2022/02/qualcomm-expands-investment-xr-and-metaverse-formation-xr-labs-europe-xr-rd/>.

¹⁹⁶ See: <https://www.sciencedirect.com/topics/physics-and-astronomy/systems-on-a-chip>

¹⁹⁷ As an example, see: Gonsher, I., Feng, P., McArn, T., & Christenson, A. 2023. Designing for Wide Adoption: An Inexpensive and Accessible Extended Reality (XR) Device. In: Stephanidis, C., Antona, M., Ntoa, S., Salvendy, G. (eds) HCI International 2023 Posters. HCI 2023. Communications in Computer and Information Science, vol 1836. Springer, Cham. https://doi.org/10.1007/978-3-031-36004-6_25

¹⁹⁸ Lang, B. 2022. Prototype Meta Headset Includes Custom Silicon for Photorealistic Avatars on Standalone. Road to VR. Available at: <https://www.roadtovr.com/meta-reality-labs-research-custom-silicon-codec-avatars-standalone-vr-headset/>.

highlight of this is the company's multi-year agreement with Meta,¹⁹⁹ signed in 2022, to continue to design customised chips for Quest products. The partnership extends the relationship between the firms, with Qualcomm's XR2 and XR2+ chips, used in Meta's Quest 2 and Quest Pro devices, respectively. For the wider market, the partnership signals that the future of XR and virtual worlds is mobile,²⁰⁰ highlighting the importance of devices needing to be lighter and more versatile.

4.6.2. Overcoming current challenges of XR adoption

Dedicated XR processors are designed to be smaller, lighter, and cooler, and to operate at low power, allowing device manufacturers to bring to market an array of sleeker, fashionable, and more comfortable XR devices. For XR and virtual worlds' applications, this is an important step to allow users to wear such devices for an extended period without the fear of discomfort or poor battery life. As an example, the UK-based company Arm, a chip design, and IP specialist, provides specialised processor technologies required to power high-performance, low-power consumer devices that will act as an entry point to XR.^{201,202} Within the XR space, Arm's chip designs are incorporated in devices, such as Meta's Quest 2 and Quest Pro, as well as Microsoft's HoloLens 2.

4.7. Graphene and metamaterials

4.7.1. Potential on XR and virtual worlds

Metamaterials are essential to the hardware development of next-generation XR systems, promoting trust in the use of immersive devices and with properties engineered to personalise the user experience. The unique properties of metamaterial include its high permissiveness of electron transport, high optical transparency, high thermal conductivity, and large specific surface area amongst others. Such properties make it amenable to innovations in terms of longer-lasting batteries, more efficient solar cells, corrosion prevention, and display panels in XR, amongst others.²⁰³ Metamaterial-facilitated power will be conditioned to enable power-up from multiple points, and prevent dropout, due to power loss. These materials will also convert energy from the environment's natural sources, such as sunlight²⁰⁴. These factors will prevent distraction and interference with the experience, and act as an enabler to maintain fully immersive engagement. If metamaterials are applied across the environment, for example by intelligent 'metasurfaces' on walls and windows, and throughout homes and offices, metamaterials will also **facilitate the connective highway**, reducing latency of data transmission and amplifying signals.²⁰⁵ Moreover, metamaterial film on windows can filter harmful rays from the sun,²⁰⁶ and allow indoor immersive activities to work through the removal of saturation of visual graphics and reduce

¹⁹⁹ Clark, M. 2022. Meta's chip deal with Qualcomm may reflect its unrealized VR ambitions. The Verge. Available at: <https://www.theverge.com/2022/9/2/23334656/meta-qualcomm-quest-vr-ar-snapdragon-xr-custom-chips/>.

²⁰⁰ Sladden, C. O. 2022. Meta and Qualcomm team up to develop the metaverse. Verdict. Available at: <https://www.verdict.co.uk/meta-and-qualcomm-team-up-to-develop-the-metaverse/>.

²⁰¹ Arm. 2022. AR, VR and XR Compute to Power the Metaverse. Available at: <https://www.arm.com/markets/consumer-technologies/ar-vr/>.

²⁰² Accelerated product development is achieved through the company's work with developers via the Arm Virtual Hardware service, removing the need to develop on physical silicon and speeding the product design process by up to two years. See: Williamson, P. 2022. Arm continues to accelerate IoT software development with new partnerships. Arm. Available at: <https://www.arm.com/company/news/2022/11/arm-continues-to-accelerate-iot-software-development-with-new-partnerships/>.

²⁰³ Edward P. Randviir, Dale A.C. Brownson, Craig E. Banks. 2014. A decade of graphene research: production, applications and outlook. Materials Today, Volume 17, Issue 9, Pages 426-432.

²⁰⁴ As an example, see: Shin, D., Kang, G., Gupta, P., Behera, S., Lee, H., Urbas, A.M., Park, W. & Kim, K., 2018. Thermoplasmonic and photothermal metamaterials for solar energy applications. Advanced Optical Materials, 6(18), p.1800317.

²⁰⁵ Bandi, A. (2022, March). A review towards AI empowered 6G communication requirements, applications, and technologies in mobile edge computing. In 2022 6th International Conference on Computing Methodologies and Communication. doi: 10.1109/ICCMC53470.2022.9754049.

²⁰⁶ As an example, see: Ko, B., Lee, D., Badloe, T., & Rho, J. 2018. Metamaterial-based radiative cooling: towards energy-free all-day cooling. Energies, 12(1), 89.

tracking fallout, creating an environment that sustains power and connectivity. It is suggested that **metamaterials are needed to fully realise XR experiences**, by contributing to miniaturisation and supporting high performance.²⁰⁷

Moreover, **graphene technologies** will form the foundation of next-generation tracking-based interfaces for human-computer interaction. Graphene-enabled technology could enhance XR technologies through the development of more immersive holographic images which are life-sized, touchable via haptic feedback, and viewable at wide angles.²⁰⁸ Graphene also has a key role to play in the **digital twin**,²⁰⁹ a virtual mirror of a product, process, or environment. In addition, graphene-based materials have the potential to enable miniaturised image sensors, as well as transparent or transformable displays. Both are key elements of XR, since they serve as efficient interfaces, in addition to conveying highly realistic images.²¹⁰

Furthermore, drawing on graphene's optical properties, a multi-layered graphene-based metamaterial has the potential to feature in XR solutions as part of ultrathin, water-proof, and flexible optical systems to enhance sensory feedback and visual immersion.²¹¹ Moreover, the stretchable and conductive nature of graphene holds potential for the **next generation of wearable haptic devices**, improving today's rigid products.²¹² Transparent graphene surfaces could revolutionise haptic feedback in mobile devices, by delivering targeted electro vibration stimuli to the user's fingertip.²¹³ Most Delphi surveyed experts agree or strongly agree (94% or 15 out of 16) that embodiment is an important field that still needs improvement and that is essential to complement the immersive experience, especially in multi-user applications. Full immersion will also become a more engaging experience, with **multi-sensory interaction**, making it more like the real world. The properties of graphene and metamaterials have also given textiles a **smart clothing** label. When woven into clothing, it would allow the clothes to offer seamless connectivity, and act as a tracking device and a connected hub.²¹⁴ Metamaterials manufactured to hold warmth and reflect heat, to match the environment can also lead to skin integration of devices - wearables that are part of you and not something you put on.²¹⁵ Smart clothes, skin, and markings give greater connectivity and tracking. They would give better security and have the potential to contribute to E-health and training. For example, thermal simulations will be given for actual events, thus helping the safety within an experience, for example, in fire safety training.²¹⁶ Metamaterials can provide training solutions that are cost-effective and can provide feedback metrics, giving more confidence to employers, reducing the reliance on physical testing and training.

Graphene will establish quicker connections between devices, due to engineered material properties, a lightweight solution to heavy installs. In addition, metamaterials offer a chance to reduce waste, size, and weight of optical lenses, which traditionally rely on glass materials, and will also have a substantial impact on devices, such as **HMDs and AR**

²⁰⁷ Abrash, M., 2021. Creating the future: augmented reality, the next human-machine interface. IEEE International Electron Devices Meeting (IEDM). (pp. 1-2). IEEE.

²⁰⁸ Ludlow B. L. 2015. Virtual Reality: Emerging Applications and Future Directions. Rural Special Education Quarterly. 34(3): 3-10.

²⁰⁹ Ali, M.A., Irfan, M.S., Khan, T. et al. Graphene nanoparticles as data generating digital materials in industry 4.0. Sci Rep 13, 4945 (2023). <https://doi.org/10.1038/s41598-023-31672-y>.

²¹⁰ Park, J., Seung, H., Kim, D.C., Kim, M.S. and Kim, D.H., 2021. Unconventional image-sensing and light-emitting devices for extended reality. Advanced Functional Materials, 31(39), p.2009281.

²¹¹ Yang, Y., Lin, H., Zhang, B.Y., Zhang, Y., Zheng, X., Yu, A., Hong, M. and Jia, B., 2019. Graphene-based multilayered metamaterials with phototunable architecture for on-chip photonic devices. Acs Photonics, 6(4), pp.1033-1040.

²¹² Pyun, K.R., Ko, S.H. 2022. Materials and devices for immersive virtual reality. Nature Reviews Materials, 7, 841-843.

²¹³ Radivojevic, Z., Beecher, P., Bower, C., Haque, S., Andrew, P., Hasan, T., Bonaccorso, F., Ferrari, A.C. and Henson, B., 2012. Electrotactile touch surface by using transparent graphene. In Proceedings of the 2012 Virtual Reality International Conference (pp. 1-3).

²¹⁴ Fernández-Caramés, T. M., & Fraga-Lamas, P. 2018. Towards the Internet of smart clothing: A review on IoT wearables and garments for creating intelligent connected e-textiles. Electronics, 7(12), 405.

²¹⁵ Younes, B. (2023). Textronics: a review of their technological aspects and applications. The Journal of The Textile Institute, 1-17.

²¹⁶ Xue, Z., Jin, P., & Jiang, R. 2023. Design and evaluation of a novel interactive firefighter clothing with multiple functionalities. Textile Research Journal, 93(1-2), 221-241.

glasses. This **structural weight reduction** will lead to reduced space requirements for components and connectivity for immersive devices and create a wider range of choices in the market of immersive devices. Graphene and metamaterials will make up a network of connected, tracked, and enhanced environments, with light weight, less intrusive, and simple tools that will help users accept new virtual worlds' technologies, **building better contextual experiences and enabling trust** from the user.

In addition, virtual worlds have seen considerable developments in the commercial sector, buying and selling are now commonplace; fashion on avatars, different styles and different personas, allow a high degree of configuration in virtual worlds. This human trait will need to become intuitive and seamless to become trusted and relevant. Graphene and metamaterials will enhance this area, turning real situations into virtual ones and allowing **control over appearance, degree of interaction, and the right to choose.** It will also allow expression and disguise, placing the responsibility in the hands of the person, and not governed by the virtual world platform. The control of immersion, which can be granted through the integration of metamaterials into physical spaces and objects (such as wearable devices) can allow virtual worlds to become a part of everyday life. For example, immersion levels controlled by an app on your phone could determine your Virtual or Augmented experience.

4.7.2. Overcoming current challenges of XR adoption

Metamaterials can overcome a wide range of challenges, which impact XR adoption. **Narrow viewing angles** associated with traditional retinal project systems can be overcome through the use of a “metamaterial mirror”, which reduces issues associated with lens movement and iris contraction with traditional approaches.²¹⁷ Relatedly, a **metasurface-based contact lens display** (CLD), which uses a holographic casting technique, could be applied to overcome the eye-accommodation issues associated with conventional CLD displays.²¹⁸ Moreover, it has been recently demonstrated how graphene oxides could enable wide-angle, full-colour, three-dimensional holograms, thanks to their electronic and optical properties.²¹⁹

Graphene-based technology could be instrumental in overcoming some of the technological challenges, which the industry is currently facing. Golparvar and Yapici²²⁰, for example, highlight the advantageousness of graphene for electrooculography (EOG). EOG-based devices **track eye movement** and relevant applications include human-computer interfaces, such as for virtual PC mousepads or keyboards, for controlling robots, for smartphone operation, and also for virtual reality gaming. Previously, EOG devices, such as goggles, masks, headbands, or headsets, have been limited in their capacity by the electrodes used for sensing eye movement, which requires the application of conductive gel. This is time-consuming and often leads to itches, swollen skin, and other allergic reactions, with prolonged use. Moreover, traditional eye-tracking systems are camera-based, and can, therefore, be both bulky and expensive. Graphene could, in theory, replace this by weaving graphene into a strong yet lightweight conductive textile.²²¹

4.8. Blockchain

²¹⁷ Ochiai, Y., 2018. How could we ignore the lens and pupils of eyeballs: Metamaterial optics for retinal projection. arXiv preprint arXiv:1804.01253.

²¹⁸ Lan, S., Zhang, X., Taghinejad, M., Rodrigues, S., Lee, K.T., Liu, Z. and Cai, W., 2019. Metasurfaces for near-eye augmented reality. ACS Photonics, 6(4), pp.864-870.

²¹⁹ Li, X., Ren, H., Chen, X. et al. 2015. Athermally photoreduced graphene oxides for three-dimensional holographic images. Nat Commun 6, 6984.

²²⁰ Golparvar, A.J. and Yapici, M.K., 2021. Toward graphene textiles in wearable eye tracking systems for human-machine interaction. Beilstein Journal of Nanotechnology, 12(1), pp.180-189.

²²¹ Golparvar, A.J. and Yapici, M.K., 2021. Toward graphene textiles in wearable eye tracking systems for human-machine interaction. Beilstein Journal of Nanotechnology, 12(1), pp.180-189..

4.8.1. Potential on XR and virtual worlds

Blockchain introduces a **new way of processing payments** in a variety of XR and virtual worlds' contexts. These include, but are not limited to, virtual experience marketplaces, AR/VR games, e-commerce, advertising, creative design and arts, tourism, and education. Blockchain-based payment systems allow users to buy virtual goods and services directly from the creators, eliminating third parties, which reduces transaction fees.²²² Precisely because of its distinct features of decentralisation, immutability, persistency, anonymity, auditability, and transparency, blockchain technology ensures that virtual payments are not only efficient, but also meet the highest security standards.²²³ Blockchain's integration with XR and virtual worlds suggests improved payments with a better experience for users and a business environment friendly to creators and innovators.

Blockchain protects data ownership and integrity, which gives rise to whole new XR sectors, and opens new avenues of online-based retail. Blockchain technology ensures that items cannot be pirated or copied, thus XR users can create and sell unique, often non-fungible token (NFT)-based digital items, including artworks. In the e-commerce and advertising sectors, blockchain can be used for trading, as well as storing information on authorship, to prevent copyright infringement and illegal redistribution. Blockchain's ability to guarantee and verify the uniqueness and immutability of the blocks of data found within it shows a lot of potential in creating a **legally and financially secure XR environment**.

Having said this, blockchain was evaluated as a less important emerging technology for the development of XR hardware and application of XR (including virtual worlds) in both Delphi survey rounds, but in the latter, sector potential was evaluated by experts to be slightly greater.

4.8.2. Overcoming current challenges of XR adoption

Blockchain can offer a solution to ethical concerns in terms of data protection and privacy and can secure the safe delivery of virtual world-based experiences. More than half (56% or nine out of 16) of Delphi survey respondents agree that the lack of secure authentication and access to highly sensitive data not on the user's device is a barrier to wide-scale XR adoption in the industrial and enterprise/defence sectors. Through seamless and intuitive virtual worlds interaction, blockchain will promote trust and acceptance among individual users and businesses.

4.9. Artificial intelligence (AI)

4.9.1. Potential on XR and virtual worlds

Artificial intelligence has a key role to play in XR technologies. Compared to other emerging technologies, Delphi survey respondents ranked AI as more important compared to other emerging technologies (51% or 26 out of 51 rated it as very important) to the development of XR. The primary motivation for developing AI-XR includes training AI, for example, to **feed AI algorithms with XR elements**; conferring intelligence on XR, by integrating AI into a particular aspect of XR to **enhance the XR experience**; and **interpreting large quantities of XR-generated data**.²²⁴ When used together, AI may assist XR in efficiently

²²² Monrat, A. A., Schelén, O., & Andersson, K. (2019). A survey of blockchain from the perspectives of applications, challenges, and opportunities. *IEEE Access*, 7, 117134-117151.

²²³ Zheng, Z., Xie, S., Dai, H.N., Chen, X. and Wang, H., 2018. Blockchain challenges and opportunities: A survey. *International journal of web and grid services*, 14(4), pp.352-375.

²²⁴ Reinert, D., Davahli, M.R., Karwowski, W. and Cruz-Neira, C., 2021. The Combination of Artificial Intelligence and Extended Reality: A Systematic Review. *Frontiers in Virtual Reality*, 2, p.721933.

interacting and communicating with people, and help to make XR and virtual worlds more immersive, intuitive, and personalised.

Moreover, the convergence of connectivity, edge computing, blockchain, and AI can strengthen and generate synergies between them, which empower XR and virtual worlds further.²²⁵ Compute-intensive AI workloads in XR can be conducted through cloud, hybrid, or edge computing, enhanced through high-bandwidth networks and AI, in conjunction with cloud technology, can more effectively handle the large-scale data that XR and virtual worlds produces.

When applied to XR and virtual worlds, AI can help to build an **autonomous and adaptive system**, which can learn and extract knowledge about the environment or rendered features within it and carry out automated decisions based on this information. The ability of AI to independently carry out decisions can improve real-time feedback and responses within the interactive environment, creating a more immersive and satisfying experience for the user.²²⁶ Moreover, potential lies in using **augmented intelligence**, which can expand and support human intelligence with the help of AI. This can result in AR assistance systems, which more flexibly react to the user's action, on the environment condition, and even detect and "understand" the status of the situation the user finds themselves in. This could help to **create context sensitivity** within more complex AR applications, such as training or maintenance.

Additionally, AI can facilitate the **detection and creation of 3D objects**, by gathering and processing data on, for example, gestures, with minimum delay and maximum accuracy. In the context of virtual worlds, this can improve efficiency, as there are increasing numbers of users (therefore 3D objects), which require large quantities of data to be processed.²²⁷ AI can also contribute to XR, and, in particular, VR and AR, through the field of **pose estimation**, which detects and tracks human movement in images and videos. AI trained with human data can better capture movement and can mitigate occlusion problems often faced in XR.²²⁸

AI is also being applied to advanced semiconductor chips. For example, **AI accelerator chips** are specifically designed to manage AI processed data. AI processing capabilities built into chips can facilitate eye-tracking and mouth tracking in device sensors to render and animate life-like and real-time user avatars.²²⁹

It is also being explored how AI can be embedded in blockchain and IoT integrated systems for data analysis and management.²³⁰ As immersion and integration into XR and virtual worlds' environments become more commonplace, data will be tracked, and transactions logged, and there is also potential for e-health monitoring and alerts. **Protective AI** has the potential to predict scenarios and prevent unsafe situations from occurring, by processing data and responding with real-time decisions²³¹.

²²⁵ Wang, Y. and Zhao, J., 2022. Mobile Edge Computing, Metaverse, 6G Wireless Communications, Artificial Intelligence, and Blockchain: Survey and Their Convergence. arXiv preprint arXiv:2209.14147.

²²⁶ Huynh-The, T., Pham, Q. V., Pham, X. Q., Nguyen, T. T., Han, Z., and Kim, D. S. (2023). Artificial intelligence for the metaverse: A survey. *Engineering Applications of Artificial Intelligence*, 117, 105581.

²²⁷ Bouachir, O., Aloqaily, M., Karray, F. and Elsaddik, A., 2022, September. AI-based Blockchain for the Metaverse: Approaches and Challenges. In *2022 Fourth International Conference on Blockchain Computing and Applications (BCCA)* (pp. 231-236). IEEE.

²²⁸ Odemakinde, E. 2023. Human Pose Estimation with Deep Learning – Ultimate Overview in 2023. Viso.ai. Available at: <https://viso.ai/deep-learning/pose-estimation-ultimate-overview/>.

²²⁹ Lang, B. 2022. Prototype Meta Headset Includes Custom Silicon for Photorealistic Avatars on Standalone. RoadtoVR. Available at: <https://www.roadtovr.com/meta-reality-labs-research-custom-silicon-codec-avatars-standalone-vr-headset/>.

²³⁰ Zheng, X.R. and Lu, Y., 2022. Blockchain technology—recent research and future trend. *Enterprise Information Systems*, 16(12), p.1939895.

²³¹ Corrales Compagnucci, M., Wilson, M., Fenwick, M., Forgó, N., & Bärnighausen, T. (Eds.). (2022). *AI in eHealth: Human Autonomy, Data Governance and Privacy in Healthcare* (Cambridge Bioethics and Law). Cambridge: Cambridge University Press. doi:10.1017/9781108921923

4.9.2. Overcoming current challenges of XR adoption

3D content generated by AI, is also essential for building large scale virtual worlds. The majority of our experts in the second Delphi survey second round agree or strongly agree (75% or 12 out of 16)) that automatic 3D content generation through AI could break through current technology limitations, and accelerate the development of virtual worlds and wider uptake of XR. AI has also found its way into XR via the so-called “**AI assisted design**” or “*AI aided design*”. This refers to the notion that AI supports the designer in understanding the model (e.g., detecting anomalies), or makes suggestions on the basis of machine-learned experiences.²³² AI assisted modelling, tracking, facial recognition, and spatial locational marking can help to build seamless integration of the real world and virtual world.

More than this, as virtual worlds are reliant on the convergence and processing of data from a range of technologies (such as IoT, digital twin, and big data), there are enhanced security risks relating to user privacy. AI application in blockchain technology can **improve security, and efficiency and reduce energy consumption**, making virtual worlds safer environments.²³³

²³² See: Suwelack. 2020. What is AI-assisted design? renumics. Available at: <https://renumics.com/blog/what-is-ai-assisted-design/>; Architectures. What is Artificial Intelligence Aided Design? Available at: <https://architectures.com/en/what-is-artificial-intelligence-and-how-do-you-work-with-it/>; Philips, M. The Present and Future of AI in Design (with Infographic). Designers. Available at: <https://www.toptal.com/designers/product-design/infographic-ai-in-design>.

²³³ Bouachir, O., Aloqaily, M., Karray, F. and Elsaddik, A., 2022, September. AI-based Blockchain for the Metaverse: Approaches and Challenges. In 2022 Fourth International Conference on Blockchain Computing and Applications (BCCA) (pp. 231-236). IEEE.

5. Overview of available virtual worlds in the EU

This chapter provides an overview of the virtual worlds that exist across the EU. Within the scope of this exercise, 180 virtual worlds were mapped according to the parameters outlined in more detail in Annex 1. The mapping of virtual worlds was implemented in January – March 2023. The following sections present an overview of the virtual worlds based on two dimensions:

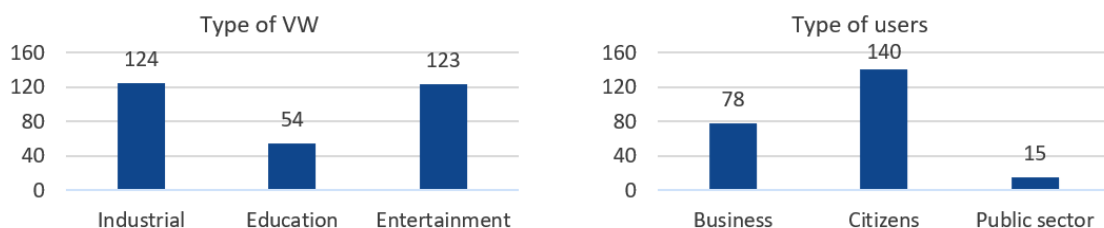
- Overview of application and users of VW - covers type, industrial ecosystem, business models and impact of VW;
- Overview of technologies to run VW - covers payment, monetisation, identity, devices, accessories and infrastructure of VW.

5.1. Overview of application and users of virtual worlds

Overview of virtual worlds

The main focus of the virtual worlds mapping exercise was on virtual worlds (VW) with industrial application. However, VWs could not fit only in this category and additional categories were identified based on the desk research – industrial, education, and entertainment²³⁴. VW, whose features can be used by enterprises to develop in different business environments, are considered to have industrial applications. VWs that provide a platform that enhances teaching methods and availability, or whose final goal is to create an alternative world of leisure activities, are considered educational and entertainment applications, respectively. Within these categories, close to 70% of the VWs mapped have industrial (124 VWs) and/or entertainment (123) applications, and just shy of 30% (54) have educational uses. As for the type of users, most of the VW target citizens (140) as their main audiences, followed by businesses (78), and then the public sector, which lags with just 15 virtual worlds targeted towards this audience (see Figure 24).

Figure 24. Type of virtual world and type of users



Note: $N = 180$. VW could be assigned to more than one category. Research conducted in January – April 2023.

Source: Visionary Analytics, 2023.

Industrial ecosystems

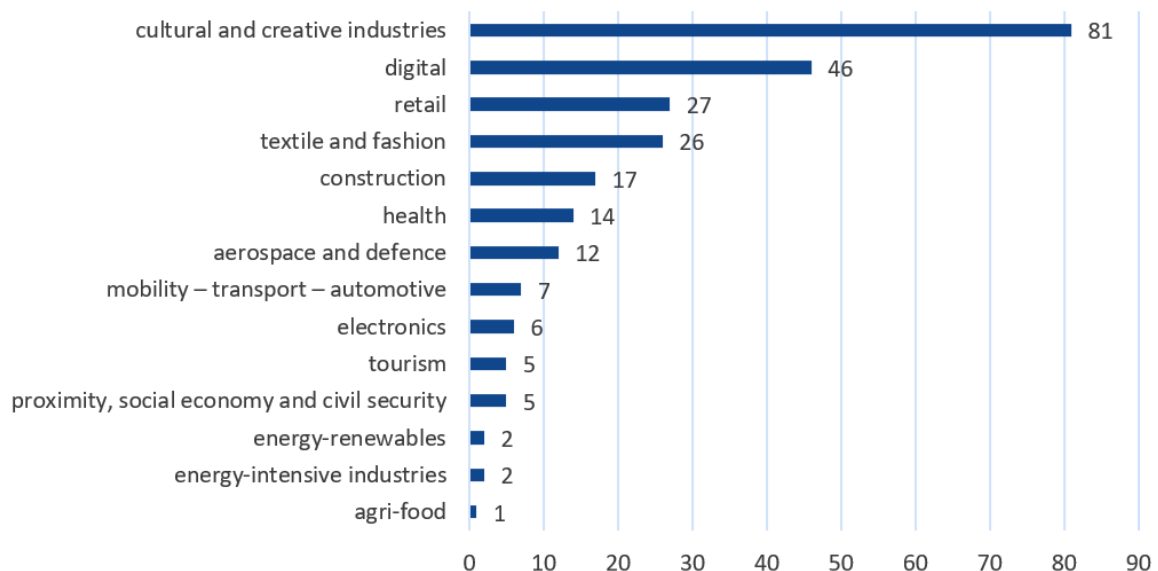
Since the majority (124 out of 180) of virtual worlds mapped have industrial applications, we assigned a specific industrial ecosystem to them. The most common industrial ecosystems were cultural and creative (81 VWs), digital (46), retail (27), and fashion industries (26), as well as construction (17), health (14), aerospace (12), or other industries to a lesser extent (see Figure 25).

Most of the cultural and creative industry VWs are focused on museums (e.g., 6529), music and concerts (e.g., *EDM metaverse* and *Musicverse*), or social media (e.g., *Sensorium*).

²³⁴ These three categories were proposed and agreed upon with the client to use in VWs mapping.

Fashion and retail industry VWs are most common in the form of advertisement (e.g., Paris Fashion Week with *Sensorium*), and revenue from the NFT market (e.g., *Shivaverse*). Additional software developments in VWs include specific applications in the industries of health, energy, and architecture (e.g., *Vault Hill City*, *ESI Group*, and *Autodesk*).

Figure 25. Distribution of VWs by industrial ecosystem



Note: $N = 180$. VW could be assigned to more than one category. Research conducted in January – April 2023.

Source: Visionary Analytics, 2023

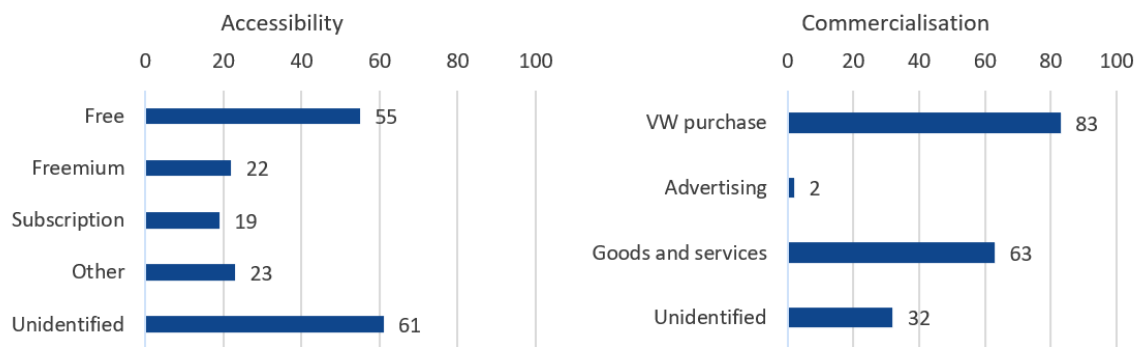
Business model

Two main business models of VWs have been identified:

- VWs oriented towards **enterprises and companies**: their accessibility is usually subscription-based and they provide services for the user. Most of these platforms are tools for virtual work environments, virtual meetings and conferences (e.g., Microsoft Mesh), or software for specific technical purposes, such as construction, design, and/or engineering (e.g., Virtual Wafer Fabrication). Due to their specialised nature, these platforms are not particularly geared towards the common citizen.
- VWs oriented towards **citizens**: these are mostly freely accessible, or freemium (with some features available for free, with upgraded versions available on a subscription basis). These obtain revenue from the VW market through the purchasing of virtual land, NFTs, or virtual accessories (e.g., The Parallel). This type of business model is predominant in VWs with an entertainment background capable of attracting a greater number of users.

Overall, 77 VWs that were mapped are free or freemium to access. 19 VWs are available on a subscription base, while 23 VWs use other access methods (mostly buying upfront). As for commercialisation, 83 virtual worlds use in-virtual-world purchase, and 63 use VW for goods and services²³⁵. The remaining VWs correspond to platforms, whose accessibility and commercialisation remain unclear (see Figure 26).

²³⁵ In-virtual-world-purchase means that VW offers the possibility to buy avatars, virtual accessories or any kind of goods needed and used in the virtual world. The virtual world used for goods and services means that customer can use VW for real-world objects or services (e.g. consultations carried on in the virtual world or VW used to see how clothes looks on different types of models in the virtual world and order piece of clothing in real life).

Figure 26. Accessibility and commercialisation of virtual world

Note: $N = 180$. Research conducted in January – April 2023.

Source: Visionary Analytics, 2023.

Evidence of impact

During the mapping exercise, the impacts of VWs were not assessed, but rather existing research pointing towards possible VW economic and social impacts have been summarised and addressed separately below.

Economically, VWs create new forms of revenue within new virtual markets and display for existing ones. *Fortnite* skins or NFT trading in *The Parallel*, are some examples of the ways in which platforms can engage users with an entertainment experience, intertwined with a virtual market of NFTs, virtual land, and other assets, where creativity is monetised. On the other hand, the development of software and simulators, and greater computational power becoming easily accessible, has a direct impact marking down build-up prices and facilitating the development and innovation process in different sectors – *VBS (Virtual battle space)* in aerospace and defence, or *Autodesk* in construction and mobility²³⁶. In addition with fast growing global spending and, with 400 million monthly active users, leaders in industries, like gaming, retail, arts, healthcare, and blockchain, are determining how to position themselves as critical players in this emerging ecosystem.²³⁷ Over the past ten years, there have been many breakthrough VWs platforms, and this trend is set to continue over the next ten years as platforms continue to be developed.

As for **social** impacts, the VWs contribute to bringing communities together to socialise, educate, and interact. Some platforms, such as *Half+half* or *HighFidelity*, promote users to socialise and collaborate in the virtual world. Others, such as *Fortnite* or *World of Warcraft*, build a community based on their gaming experience. Lastly, platforms, such as *TechStar* and *Soccoco*, are aiming to create a virtual environment where lectures, presentations, and calls can take place.

In addition, the impacts are both positive and negative. On the one hand, the VWs create an endless number of opportunities, including for gaming, socialising, and education, as well as for different industries (e.g., health, engineering, construction, energy and digital). However, niche industry-based VWs are less known because of smaller user pools. For example, as opposed to popular gaming platforms, such as *Fortnite*, fewer people will engage with niche platforms, such as *PowerWorldSim*²³⁸, which allows users to measure the power grid in their local area, or *Energy3D*²³⁹, which allows users to visualise how best to build a house and maximise its solar power output. Furthermore, the technologies being developed for VWs are enhancing computing power availability for a multitude of industries, including construction, energy, and health, which can have a positive impact on humanity.

²³⁶ The Economist, 2020. Headset technology is cheaper and better than ever. Available at:

<https://www.economist.com/technology-quarterly/2020/10/01/headset-technology-is-cheaper-and-better-than-ever>

²³⁷ Geri Mileva, "52 Metaverse Statistics | Market Size & Growth (2023)". Available:

<https://influencermarketinghub.com/metaverse-stats/>

²³⁸ See: <https://www.powerworld.com/>

²³⁹ See: <https://energy.concord.org/energy3d/index.html>

On the other hand, the use of these platforms has generated concerns regarding the potential negative effects on children's personal and social development.^{240,241}

5.2. Overview of technologies used to run virtual worlds

Payments, monetisations, and identity

There are two main technological trends in VWs defining monetisation and identity systems: centralised and decentralised. The former is the classic form of web development, whereby the stream of information is owned by the platforms, whereas the latter aims to decentralise the data flow from developers to users. These systems are mainly defined by Web2.0 and Web3 technologies²⁴² (see Table 14). Of the 120 VW where types of monetisation and identity systems were identified, 46 were centralised (Web 2.0) and 74 - were decentralised (Web3).

Table 14. Web 2.0 and Web3 differences

	Web 2.0	Web3
Data storage	Centralised	Decentralised
Platform format	PC/console; Virtual reality/augmented; reality hardware; Mobile/app	PC/console; Virtual reality/augmented; reality hardware; Mobile/app coming soon
Payment infrastructure	Traditional payments (e.g., debit/credit cards)	Crypto wallets
Digital asset ownership	Leased within the platform where purchased	Owned through nonfungible tokens (NFTs)
Digital asset portability	Locked within platform	Transferable
Payments	In-platform virtual currency (e.g., Robux for Roblox)	Cryptocurrencies and tokens
Content revenues	The platform or store earns a part of the purchase, and the rest goes to the developer	Peer-to-peer; developers or content creators directly earn revenue from sales

Source: Visionary Analytics, based on Onyx by J.P. Morgan, JPMorgan.com, 2022. "Opportunities in the metaverse: How businesses can explore the metaverse and navigate the hype vs. reality", in McKinsey & Company, 2022. Value creation in the metaverse. The real business of the virtual world.

In addition, we looked at whether VWs use blockchain, Non-Fungible Tokens (NFTs), virtual land, and what payment gateways are used. Out of 180 VWs analysed, slightly less than half (88 VWs) of VWs use NFTs, while only just over one quarter (49) use virtual land²⁴³ (see Figure 27).

Together, blockchain and Web3 represent the latest developments in technology, founded on the concept of organising items by blocks of information that are interlinked to create a chain within a decentralised peer-to-peer network. This method makes items unique and transactions irreversible, where records of blocks cannot be altered retroactively without the alteration of subsequent blocks. On the other hand, market based and Web2.0

²⁴⁰ Henz, P. The societal impact of the metaverse. *Discov Artif Intell* 2, 19 (2022). <https://doi.org/10.1007/s44163-022-00032-6>

²⁴¹ Bernard Marr "The Effects Of The Metaverse On Society", Forbes, 2022. Available: <https://www.forbes.com/sites/bernardmarr/2022/04/04/the-effects-of-the-metaverse-on-society/?sh=3554464d765b>

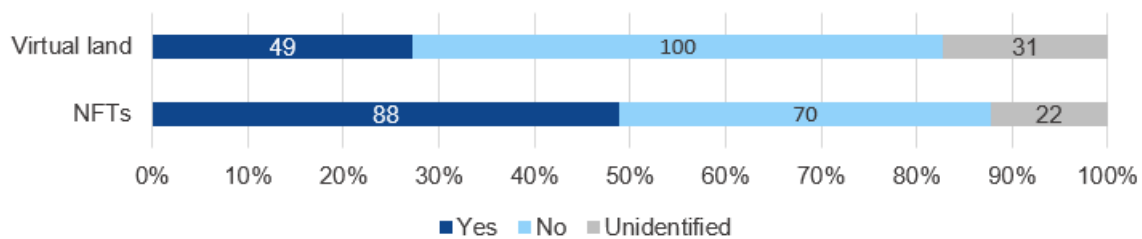
²⁴² McKinsey & Company, 2022. Value creation in the metaverse. The real business of the virtual world

²⁴³ Virtual land in the metaverse and virtual worlds refers to digital plots or parcels of land that can be owned, bought, and sold by individuals or organizations. It allows users to create, interact, and monetise within these virtual spaces, offering opportunities for personal expression, social interactions, artistic creations, gaming experiences, virtual commerce, and investments. Virtual land ownership introduces a sense of digital scarcity and ownership rights, shaping the immersive experiences of users in the metaverse.

environments rely on a traditional financial system that uses financial intermediaries, and where all transactions are centralised in the platform. Traditional payment methods, like credit/debit card or PayPal, are still widely used, although they are being displaced by the use of cryptocurrencies²⁴⁴.

Overall, the 180 VWs mapping exercise showed a trend that the latest platforms and technologies in VWs are aimed towards blockchain/Web3. This perception, in some respect, bridges the gap between the ‘virtual world’ and real life, where the items of an avatar (apartment, land, car, etc.) are as unique, and as real, as a user’s own apartment, land, or car. This is achieved through blockchain, which creates a unique history for each item, as is true of any item in real life.

Figure 27. VW distribution by usage of NFTs and Virtual land



Note: N = 180. Research conducted in January – April 2023.

Source: Visionary Analytics, 2023.

Devices, OS and accessories

The devices on which a VW is accessible contribute to the success of the platform. The devices affect the level of immersion that the user can achieve, but it can also limit access to only those in possession of the specific device needed. During the mapping exercise, it was noted that most of the VWs are accessible via desktop or mobile devices (118 VWs (out of 180) and 73 VWs respectively), or by both simultaneously (62), while VR (68) and AR (19) headsets, gaming consoles (11) and specialised devices (11) are in considerably less use.

On the one hand, some devices (VR, AR, or specialised input devices) can make the experiences or perspectives of the VW more real. For example, *Virtual Battle Space (VSB)* uses a lot of equipment to make its experience an ultimate virtual reality for the most effective application in training the army²⁴⁵. However, on the other hand, the need for such hardware to access the platform will reduce the pool of users to which it is accessible. Thus, the majority of VW are developed to be most accessible (meaning that they will be available for mobile devices or desktops, e.g., *SecondLife*, *Roblox*, *Portals*). At the same time, many platforms are also developing access to the VW with VR devices simultaneously (however, few VWs are only available using VR/AR devices, and not via desktop/mobile). More technical platforms have a clear market defined and will use VR/AR (*ANSYS*, *SpaceVerse*, *Immersys*), or desktop/mobile devices (*Autodesk*, *Energy3D*, *PowerWorldSim*), to conform with the needs of that particular audience.

Infrastructure

The infrastructure upon which each VW is built differs greatly depending on when it was built (technological advancement during years matters), for which purpose it was built and its technical development implemented during years. To gain a better understanding of the infrastructure used in VWs, we looked at factors, such as the type of cloud or edge

²⁴⁴ McKinsey & Company, 2022. Value creation in the metaverse. The real business of the virtual world

²⁴⁵ See: <https://vbs4.com/>

computing used, the use of AI or streaming technologies, and the types of engines used in VWs. Some findings are as follows:

- The VW mapping exercise revealed that Software as a Service and Gaming as a Service²⁴⁶ (SaaS – 94 VWs; GaaS – 25VWs) were the most commonly used and most user-friendly **cloud computing** infrastructures.
- **Streaming** technologies (47 VWs), are mostly used by VWs focused on facilitating real online engagement between users, e.g., *Hoppin' World*, *Twitch*, *Viverse*.
- **AI** is a new technology being developed and implemented in VWs (43 VWs), leveraging machine learning algorithms or AI customisation software, e.g., *StarAtlas* and *IMVU*.
- Lastly, Unity and Unreal **engines** are the most popular among VWs, while more technical VWs, e.g., *Concept3D*, *VBS*, or *Decentraland* tend to use their own proprietary engines.

Each individual VW uses a combination of tools that fit their unique needs. For example, some VWs might adopt AI and blockchain, and be accessible via VR headsets, while others may adopt blockchain with no NFTs and accessible only via mobile devices. Modern technologies, while still in the early stages of development, are transforming VWs. Web3, blockchain, AI, NFTs, and cryptocurrency are booming, and seem to represent the future of VW in all senses. Blockchain, cryptocurrency, and Web3 are tightly connected in the form of a decentralised environment that promises to provide a more secure experience in the virtual world and, more generally, on the internet. Artificial intelligence pledges to help create a more realistic virtual world with fewer software complexities. Lastly, NFTs are the items that will make each user's experience in VWs unique.

²⁴⁶ Software as a Service (SaaS) offers fully managed virtual worlds that users can access and interact with over the internet. This eliminates the need for virtual world developers to build and manage their own infrastructure but also limits their ability to customise and control the virtual world.; Gaming as a Service (GaaS) offers cloud gaming solutions that allow users to stream and play high-end games without the need for high-end hardware. This can be used to run virtual worlds and other immersive experiences with high-end graphics and physics.

6. Conclusions and recommendations

This study presented an analysis of the XR landscape, XR and virtual world-related public initiatives, emerging technologies, and their potential impact on XR and virtual worlds development, in addition to an overview of virtual worlds available in the EU. This section presents the key conclusions of the study and a set of recommendations for specific EU-level policy measures and actions. The recommendations aim to foster the development and adoption of XR technologies, improve EU's industrial competitiveness in particular in a zero-distance economy, as well as to support the XR ecosystem.

Study conclusions and recommendations were derived from a combination of methods, including stakeholder consultations (i.e. 49 interviews, a Delphi survey of 109 experts), desk research (i.e. collection of background information on the XR industry in Europe across different ecosystems, identification of good practices, analysing emerging technologies relevant to XR, mapping virtual worlds), attendance of XR-related events, and were scrutinized by XR and EU policy experts during two online workshops.

According to the analysis, six key themes emerged as the most prominent to conclude on. The recommendations following each conclusion are not presented in a ranked order as they would all have to be tackled in order to holistically address the underlying needs and barriers or take stock of the opportunities XR technologies have to offer.

Provide a medium for fostering collaboration and exchange among stakeholders, as well as addressing current and future challenges related to XR and virtual worlds

As referred to in Section 2.4.2 (Business barriers), the study found that the **EU XR market is fragmented**. Differences in regulation, preference for national or regional industries and entities divide the European market into smaller, national, or even regional or local components. This situation leads to difficulties in upscaling successful XR solutions and establishing businesses on a cross-national basis.

At the same time, as described in Section 2.4.5 (Legal barriers), the industry is facing challenges with the **uncertainties of the regulatory framework** in the context of XR and virtual worlds. For example, the nature of the content produced for XR and virtual worlds complicates establishment of clear ownership and control of IP, as the current regulatory framework in the EU and at the global level does not properly define artistic content. In addition, the ethical implications of XR are largely unexplored (due to their complexity and novelty) and clear behavioural guidelines at the policy level are yet to be established. Moreover, data security and protection against cyber attacks provide additional legal challenges when handling sensitive data, which requires a strong regulatory framework to avoid misuse of data.

Specific policy actions by the European Commission that could address this include the following:

- Bringing together stakeholders into a **policy body** (e.g., working group, expert group, task force etc.) focusing on XR technologies related to virtual worlds. The body could focus on providing guidelines/ roadmaps for European policy, as well as for companies and practitioners detailing the procedures to be followed when testing, developing, validating, distributing, or applying solutions involving new technologies (including ethical, legal, data protection issues, among others). This could ensure that legislation and policy are not (far) behind the latest developments in XR and virtual worlds, and, furthermore, that they do not hinder the development of XR technologies. Alternatively, these functions could be also integrated into existing body(-ies) e.g., the VR/AR Industrial Coalition.

- **Offering a platform** (e.g., an observatory), or promoting an existing platform (e.g., European Cluster Collaboration Platform), to raise awareness of the different stakeholders and public and private initiatives across Europe in relation to XR and virtual worlds. Such a platform could serve as a space for exchange between existing community-building initiatives and stakeholders, creating synergies and coalitions. It could also serve to inform stakeholders about the progress and latest developments of the European industry and showcase unique emerging companies, use cases or initiatives.



High-level expert group on AI or the various Observatories (on Blockchain, on the Online Platform Economy, or the Digital Media Observatory) could inspire the structure of such a body. It is also important to come up with a good model of cooperation between national, European, and pan-European stakeholders.

Promote a globally-oriented EU XR industry

EU players have limited importance in the global XR market as opposed to the influence exerted by non-EU actors. As described in Section 2.4.2 (Business barriers), American players dominate the platform landscape (at least in the Western market), with distributors such as Oculus Quest Store and Steam. The landscape of hardware manufacturers is more diverse with the US, Japan, China, and South Korea housing the biggest manufacturers (such as Oculus, Sony, HTC, Pico, etc). Dominance of non-EU players has direct consequences on XR-related content production and distribution, often limiting the ability of European creators and policymakers to shape the market.

Specific policy actions by the European Commission (facilitated by Member States) that could address this include the following:

- Facilitating the **creation of an XR cluster** connecting different stakeholders (large companies, SMEs, research organisations, education institutions, etc.). The cluster would allow to enhance cooperation, bring together European competencies and capabilities, and could provide better chances to compete with large global players. As a cluster, European entities could have a stronger position to enter into partnerships with key non-European players.



The feasibility and potential interest from among the stakeholders in the creation of this cluster should be assessed by the European Commission beforehand.

Ensure users' awareness of XR technologies and access to talent for EU's XR industry

As referred to in Section 2.4.4 (Societal barriers), **business professionals and/or end users lack awareness of XR technologies**. Both groups across various sectors have limited knowledge about benefits that XR technologies can bring and their market potential in various markets. As a result, businesses and consumers do not integrate/purchase XR solutions as they do not know or are sceptical about their potential. In addition, businesses approach XR studios without a clear idea of how the technology can practically solve their existing issues and without knowledge of the costs/efforts implied for implementation, leading to sub-optimal results.

There is also **resistance from users** in transitioning from a traditional to an XR solution (more details can be seen in Section 2.4.4). This is especially true in B2B applications, as company staff need to be effectively trained on how XR can impact their everyday work and why the company decided to use the new technology. Providing a clear rationale can help overcome the initial reluctance.

Finally, XR solution providers across various ecosystems **lack staff with the required technical expertise** to develop or help businesses to install and operate XR technologies.

Specific policy actions that the European Commission could jointly initiate with Member States could address this include the following:

- Develop a model and/ or guidelines for **integrating XR as a part of different education programmes** (not only in computer science, but also in engineering, architecture, medicine, business and management, natural sciences, art, etc.) at different education levels (including non-formal education).
- Provide funding to **strengthen existing XR-related programmes/ subjects**, or establish new ones at tertiary education institutions in the EU at all levels – Bachelor, Master, and Doctorate studies. DG CNECT could allocate funding for XR-related study programmes/ subjects under the Digital Europe programme (under Strategic Objective 4), and/ or through the Erasmus+ programme. Such programmes could cover the whole range of skills from enabling technologies to the final user experience of XR applications.
- **Incentivise stakeholders** (e.g. associations) across different industries to **prepare trainings** for people working in their industry on the use of XR applications and technologies and **facilitate awareness-raising initiatives** to communicate success stories (e.g., through pilot demonstrators and hands-on opportunities to test the technologies), and the specific benefits for XR users. Promote XR exhibitions, festivals, workshops, conferences, hackathons, competitions, networks, webinars, and public showcases to raise awareness of existing XR solutions and expand the potential user base. The Commission could also encourage current event organisers (e.g. Stereopsia, AWE, among others) to cooperate, in order to have a larger pan-European event bringing most European stakeholders together.

Increase funding and financing opportunities for XR entities at different growth stages

Access to funding was highlighted as a key financial barrier impacting the adoption of XR technologies. XR financing analysis in Section 2.1.1 revealed a steady increase in private funding raised by XR companies in the EU since 2016. However, EU is behind other regions, such as the US, in terms of access to funding for XR companies. As described in Section 2.4.3 (Financial barriers), accessing private funding opportunities in the EU is also complicated, as European investors seem to be more risk-averse compared to e.g. American investors, and the market potential (e.g. data about the return on investment) of XR technologies is still unclear. In addition, private sector funding is more often available at the beginning of a venture, through seed or early-stage VC funding. This means that it is potentially more difficult for mid-size companies to finance their scale-ups.

Public funding at EU- and national-level is often insufficient to meet the specific requirements of individual ecosystems (more details are provided in Section 2.4.3). While stakeholders often provided positive feedback about EU-level funding opportunities, such as Creative Europe, there is a need for more substantial budgets, as currently not all high-quality proposals get funded, due to fierce competition. In addition, simplification of administrative requirements to the highest extent possible is needed, since SMEs and start-ups particularly tend to struggle to find and allocate the resources necessary to apply for public opportunities.

Specific policy actions that the European Commission, together with the EIB, could address this include the following:

- Provide funding for the **creation of a European venture capital fund** dedicated to investments in XR companies and focusing not only on early phase, but on scaling-

up as well. This fund could be set up and administered by the European Investment Bank, which manages similar measures funded through the European Regional Development Fund (e.g., the JEREMIE initiative²⁴⁷). In addition, a fund providing guarantees or other incentives for investors and XR businesses would promote the attractiveness of investing in XR.



The European Commission should liaise with the EIB to discuss feasibility of such instruments. A working group consisting of DG CNECT, the EIB, DG RTD, and other relevant DGs could also be set up to either develop a new funding instrument, or to set up an XR-focused fund within the currently available funding instrument(s).

- **Continue and expand the focus on XR within existing support mechanisms**, such as Horizon Europe, Creative Europe, and Digital Europe, which have been proven successful in promoting R&D and content development in XR. More specific adjustments could be made in the following areas:
 - Adjusting funding schemes targeting XR industry to reflect the multidisciplinary nature of the industry, and/ or facilitate the blending of different funding sources, for instance funding schemes addressing joint technical development of solutions and creative content components.
 - Supporting the scaling-up of companies with existing solutions with the potential to develop into XR hardware, platforms, or virtual worlds. XR should be targeted directly by flagship initiatives and be within the scope of the European Digital Innovation Hubs.
 - Increasing the number of small funding opportunities without highly specific requirements, and, with simple application procedures, reducing red tape and ensuring wider accessibility of these opportunities by all types of stakeholders active in XR development.

Support XR standardisation efforts

Insufficient standardisation efforts in the EU (and at the global level), as described in Sections 2.3.3 (Infrastructure needs) and 2.4.1 (Technological barriers), often result in issues related to interoperability, which hinder the possibility of developing new applications or monetisation of existing applications. Different hardware and software providers offer their proprietary solutions which may not be compatible with each other, further complicating standardisation efforts.

Specific policy actions that the European Commission, together with relevant national authorities of Member States, could address this include the following:

- Develop a **European strategy for XR standardisation**. The strategy should define EU's aims in the global XR standardisation process, and foresee measures on how to achieve these aims (e.g., facilitating European stakeholder engagement in international standardisation processes).
- **Raise awareness** about the situation in XR norming scene, available standards related to XR, working groups working on new standards, and similar topics among European stakeholders.

Monitor the development of virtual worlds

As can be seen from the overview of virtual worlds in Chapter 5, virtual worlds vary in terms of their users and domains targeted, business models, technologies used to run them, quantitative and qualitative impacts on people and businesses. Virtual worlds are also relatively new phenomena, thus their landscape is constantly changing. In addition,

²⁴⁷ http://www.eif.europa.eu/what_we_do/resources/jeremie/index.htm

European Commission Communication on Web 4.0 and virtual worlds²⁴⁸ highlighted that it is crucial **to keep up with the developments of virtual worlds**, their impact on people, various types of industry users, market movements, and on new technological developments.

Specific policy actions that the European Commission (or a policy body/ observatory, as proposed above) could address this include the following:

- Periodically **monitor the development of virtual worlds** in the EU in a structured way, focusing at least on the number of virtual worlds in the EU, type of users targeted, application domains, business models, technologies used to run virtual worlds (including their accessibility), evidence about quantitative and qualitative impacts of virtual worlds on people and businesses. Further dimensions should be identified and added to the monitoring framework to capture any additional elements of virtual world evolution that are relevant to policymakers.

²⁴⁸ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU initiative on Web 4.0 and virtual worlds: a head start in the next technological transition, 2023 July 11.

Annexes

Annex 1: Detailed methodological approach

(Exploratory) Desk research

Desk research was used throughout different project phases and tasks. Exploratory **desk research** helped to review and build upon the existing knowledge-base, in order to further develop operational questions, and improve the design of study methods. Exploratory desk research helped to develop the list of stakeholders that were engaged during the interviews, Delphi survey, and workshops. **Desk research** allowed to collect the background information on the XR industry in Europe across different ecosystems (Task 2), and prepare the directory of the XR industry associations (Task 3). In addition, desk research laid foundations to the Delphi survey, by analysing emerging technologies relevant for XR, and allowed to map virtual worlds (Task 5). The detailed approach to desk research, used for collecting data for each task, is presented in more detail below. The list of sources analysed is provided in Annex 2.

Landscape analysis (Task 2)

Desk research focused on market research reports, academic and web articles, relevant events' outcomes, sectoral reports, academic papers, and project teams' internal database of companies, encompassing all industrial ecosystems. To the extent possible, desk research focused on the 14 industrial ecosystems, as outlined in the European industrial strategy.²⁴⁹ This inclusive view ensures a thorough understanding of the breadth and depth of XR technology deployment and its implications for the future of European industry.

While data collection started in parallel for all the industrial ecosystems, we first performed the pilot analysis for four selected ecosystems. The selection of the pilot sectors is mostly based on the existing project team's experience, which facilitated research efforts. Therefore, the following industrial ecosystems were selected for pilot: Energy-intensive industries, Construction, Aerospace and defence, Cultural & creative industries, and Digital. For each sector the study team answered the research questions, providing an analysis of the importance of the ecosystem in the overall European XR landscape, with a focus on the level of deployment of XR technologies, most promising trends, applications, and domains, as well as main observed needs, challenges, and opportunities.

All remaining sectors were analysed after the pilot analysis was completed. The methodological approach was organised into different phases. First, we identified various application areas of XR. The compilation of these applications was informed by previous studies and supplemented with an extensive review of the related literature. An illustrative summary of the principal application domains is delineated in the subsequent table.

Table 15. Overview of the XR applications areas identified

Classification of applications
Content production
Data visualisation and simulation
Design

²⁴⁹ https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en

Classification of applications
Entertainment and cultural experiences
Marketing, promotion, and sales
Other
Planning and process management
Quality control, diagnosis, and maintenance
Remote collaboration
Training and education
VR/AR/other technology provider

Source: Authors' own elaboration.

Next, we conducted an in-depth analysis of the main exhibitors of VR/AR technologies at the most relevant European XR events. The exhibitors' solutions - their products, solutions, and services - were then categorised within a two-dimensional matrix, defined by two primary variables: application area and industrial ecosystem. This matrix provided a preliminary overview of the XR technological deployment within each industrial ecosystem. To further complement these findings, we interviewed key XR stakeholders in each industrial ecosystem. The aim was to obtain a range of perspectives and industry-specific insights.

Finally, we conducted a comprehensive literature review for each industrial ecosystem, examining the current state of VR/AR usage, its benefits, and potential future applications. In addition, we also reviewed data gathered from over 30 companies within each ecosystem, accessed from public sources. This additional information deepened our understanding of XR usage, and its implications across different industries.

Desk research was also used for the analysis of relevant EU financing databases to provide general descriptive statistics and a qualitative analysis on the types of XR projects financed, along with providing potential examples of good practices and contacts relevant for the interviews. Database was screened per relevant keywords (e.g., VR, AR, metaverse, XR, headset). The main data was extracted from Horizon 2020 and Horizon Europe project database.

We have also analysed other relevant EU financing databases specific to particular ecosystems (e.g., Creative Europe for the cultural and creative sector), and manually checked other sources, such as EIT Digital and national cases to complement the financing analysis. The public funding databases analysis was complemented by other databases, such as Crunchbase and Dealroom, which provide data on start-ups and tech ecosystems. This data was also complemented with public procurement analysis from Tenders Electronic Daily (TED) from 2017 onwards, which is further described under Task 4 (Inventory of public initiatives).

Directory of XR associations (Task 3)

The starting point of the directory was a list of XR industry associations in the EU Member States gathered as part of the study "extended Reality: opportunities, success stories and challenges (health, education)", commissioned by DG CNECT, Unit G2. This directory of XR industry associations was created for the purpose of distributing the survey. The directory was compiled by searching for the XR-related associations on the internet and validating it with DG CNECT and project advisory board members. It can, therefore, be

considered an exhaustive list of XR industry associations in the EU Member States. This list collected by Visionary Analytics was reviewed and validated by Ecorys (who have already been in contact with many XR associations in previous assignments). In addition, the list also includes the main global associations (which is outside of the requested scope for this Task).

Next, the project team identified associations in Horizon Europe associated countries (HEAC). We firstly employed desk research, by compiling a list of keywords in English relevant for finding such associations. We also translated the keywords into respective national languages, to facilitate the search of national sources. The long list of keywords in English is presented in the box below.

Keywords used for identifying associations via desk research

- a. Permanent keywords (do not change in every search): XR, VR, AR, MR, immersive technologies, metaverse, virtual worlds (incl. both abbreviations and full phrases).
- b. Country-specific keywords (used for searches focusing on different countries): all EU MSs separately, all HE-associated countries separately, as well as regional names, i.e., European, Baltic, Nordic, African, Asian.
- c. Words related to the type of entities: association, community, hub, institute, centre, alliance, forum, academy, initiative, cluster.

In order to optimise the search, the keywords were applied using logical operators (AND, OR), to connect different groups of keywords (e.g., permanent + country-specific + entity-related). For example (XR OR extended reality OR VR OR virtual reality OR virtual-reality OR AR OR augmented reality OR MR OR mixed reality), AND (Lithuania), AND (association OR community OR hub OR institute OR centre OR alliance OR forum OR academy OR initiative).

Once the search in English was completed, the process was repeated using search terms translated into the national languages (e.g., in Lithuanian: 'išplėstinė realybė' AND 'asociacija' AND 'Lietuva').

The project team has also used additional strategies to identify relevant associations:

- Checking if any association representatives participate in the events that we attended as part of Landscape analysis.
- Checking if any associations are mentioned in the sources analysed during Landscape analysis.

Furthermore, we used a combination of desk research, interviews, and ad-hoc contacts with associations (email or phone exchanges), to collect relevant information about all associations. The algorithm for collecting relevant information was as follows:

- Desk research of publicly available sources was used to harvest all available information online – websites of associations, policy reports, news articles, conference materials, etc.
- If some information was not available via desk research (e.g., Lead person, partners and members) – we contacted the associations directly via email and followed up with a phone call.

The final directory contains 147 associations.

Analysis of public initiatives, public procurement and funding opportunities (Task 4)

The starting point of the directory of **public initiatives** was a list of public initiatives in the EU Member States gathered as part of the study “extended Reality: opportunities, success stories and challenges (health, education)”, commissioned by DG CNECT, Unit G2. This list was prepared by analysing XR-related opportunities, success stories, and challenges in the health and education sectors. The list was compiled using the following data collection methods: desk research, interviews, survey, public procurement analysis.

This list was then complemented via desk research, interviews, and ad-hoc contacts (same approach as for the Directory of XR associations), to include public initiatives in HEAC. In addition, when contacting associations for the Directory of XR associations and other stakeholders for the Landscape analysis, we also took the opportunity to ask them whether they know of any policy initiatives in the countries they are active (notably, this was preceded by desk research – interviews were not the main elements of the approach).

These public initiatives were analysed and compared, and their impact on the European XR industry and the EU internal market at large was assessed. In order to carry out this analysis, we collected the following information for each public initiative:

- Geography (EU or HEAC)
- Country
- Contact details
- Title of public initiative
- Website
- Description of public initiative
- Type of initiative (policy measure, action, plan, instrument, etc.)
- Actors involved in the implementation
- Key actions foreseen
- Expected impact (as described by the authorities themselves)
- Foreseen funding
- Share of project costs covered by the initiative per funded project
- Timeline
- Number/types of beneficiaries (link to the list of beneficiaries, if available)

Out of the information collected as outlined above, we added additional analytical categories to facilitate data analysis:

- Whether industry actors were involved in implementation or not
- Whether educational institutions were involved in implementation or not
- Whether the initiative had a specific geographic/area focus or not

- Whether the initiative had a specific industry focus or not
- Primary area of intervention of the initiative – standardised categories that were derived using a bottom-up approach:
 - **Adoption of XR/AR/VR solutions.** Examples include using XR solutions to boost tourism by making cultural heritage accessible to a broader audience, facilitate training (including simulators in aerospace and defence and various educational applications), promote cohesion in local communities (such as through a virtual platform collecting citizens' ideas on local area transformation), and address stress, pain, and mental health-related issues.
 - **Access to XR/VR/AR infrastructure.** These initiatives provide facilities (spaces, tools, laboratories, technology, etc.) for companies, startups, researchers, and individuals to create products, or gain expertise and knowledge in the field.
 - **Promotion of XR/AR/VR solutions.** These initiatives focus on the organisation of various events, such as festivals, workshops, conferences, hackathons, competitions, networks, webinars, and public showcases, to raise awareness of existing XR solutions and expand the potential user base.
 - **Industry intermediation services.** These initiatives offer a comprehensive set of services to the industry, including knowledge transfer, facilitating fundraising, networking, business mentorship, training, and research. They often provide access to XR infrastructure and organise promotional events.
 - **XR/AR/VR-related education, training, and skill development.** These initiatives concentrate on incorporating XR-related content into ICT educational curricula, or providing training themselves, to ensure the development of necessary skills.
 - **Research and roadmaps.** These initiatives are dedicated to conducting applied and fundamental research in the field of XR to catalyse the development and deployment of XR technologies.

To aid desk research, we compiled a list of keywords in English relevant for finding such public initiatives. We have also translated the keywords into respective national languages to facilitate the search of national sources. The long list of keywords in English is presented in the box below.

Keywords used for identifying public initiatives via desk research

- a. Permanent keywords (do not change in every search): XR, VR, AR, MR, immersive technologies, metaverse, virtual worlds, virtual (incl. both abbreviations and full phrases).
 - b. Country-specific keywords (used for searches focusing on different countries): all EU MSs separately, all HE-associated countries separately, as well as regional names, i.e., European, Baltic, Nordic, African, Asian.
 - c. Words related to the type of search: public initiative, initiative, policy, public policy, measure, action, plan, instrument.
- In order to optimise the search, the keywords were applied using logical operators (AND, OR) to connect different groups of keywords (e.g., permanent + country-specific + search-related). For example (XR OR extended reality OR VR OR virtual reality OR virtual-reality OR AR OR augmented reality OR MR OR mixed reality OR metaverse OR virtual world OR virtual), AND (Lithuania), AND (public initiative OR policy OR measure OR action OR plan OR instrument).
- Once the search in English was completed, the process was repeated using search terms translated into the national languages (e.g., in Lithuanian: 'išplėstinė realybė' AND 'iniciatyva' AND 'Lietuva').

The final directory contains 122 public initiatives.

In addition to the directory of public initiatives, we also assessed the XR-related (including the virtual worlds) initiatives present in the directory, focusing on the following aspects:

- Geographic distribution of initiatives (presence/absence of XR initiatives in certain countries/regions)
- Comparison of initiatives in terms of their scope (e.g., objectives, timeline, budget, type of initiative, beneficiaries/target groups)
- A general assessment of the impact the initiatives may have for the European XR industry and the EU internal market at large (e.g., if the initiative removes significant legal or other roadblocks to industry development, significant funding opportunities are available, etc.)

We employed the same approach to produce the inventory of **public initiatives in third countries** (desk research, ad-hoc contacts, and interviews). In addition, in all of our contact efforts, we asked any associations or public authorities in the EU and HEA countries about any third-country public initiatives they may be aware of.

We collected the following data on each of the public initiatives:

- Geography (continent)
- Country
- Title of public initiative
- Website
- Description of public initiative

The inventory of initiatives (48 initiatives in total) served as a long-list from which we selected a short list of 8 relevant initiatives on which we conducted case studies (see section on 'Case studies below').

We have also employed desk research to map main **funding opportunities** for providers of XR solutions and technology (both hardware and software) at European-, national-, and regional-levels in EU MSs and HEAC. The analysis of funding opportunities also covered national recovery and resilience plans.

We collected the following information for each funding opportunity:

- Geography (EU or HEAC)
- Title of funding opportunity
- Website
- Description of funding opportunity

Out of the information collected as outlined above, we added additional analytical categories to facilitate data analysis:

- Whether the funding opportunity had a specific sectoral focus or not
- Whether the funding opportunity had a specific target group or not

- Whether information on budget of the opportunity was available or not

To aid in desk research, we compiled a list of keywords in English relevant for finding such funding opportunities. We also translated the keywords into respective national languages to facilitate the search for national sources. The long list of keywords in English is presented in the box below.

Keywords used for identifying funding opportunities via desk research

- Permanent keywords (do not change in every search): XR, VR, AR, MR, immersive technologies, metaverse, virtual worlds, virtual (incl. both abbreviations and full phrases).
 - Country-specific keywords (used for searches focusing on different countries): all EU MSs separately, all HE-associated countries separately as well as regional names, i.e., European, Baltic, Nordic, African, Asian.
 - Words related to the type of search: funding, loan, grant, financing, financial support.
- In order to optimise the search, the keywords will be applied using logical operators (AND, OR) to connect different groups of keywords (e.g., permanent + country-specific + search-related). For example (XR OR extended reality OR VR OR virtual reality OR virtual-reality OR AR OR augmented reality OR MR OR mixed reality OR metaverse OR virtual world OR virtual), AND (Lithuania), AND (funding OR loan OR grant OR financing OR financial support).
- Once we exhaust the search in English, we will repeat the process using search terms translated into the national languages (e.g., in Lithuanian: 'išplėstinė realybė' AND 'finansavimas' AND 'Lietuva').

The final directory includes 92 funding opportunities.

As for the data on **public procurement**, we have built on the outputs of the aforementioned study “extended Reality: opportunities, success stories, and challenges (health, education)”, which also produced an overview of public procurement related to XR. The study team was extracting information from Tenders Electronic Daily (TED), as well as national procurement databases in the case of HEAC, and collecting data on procurement published between January 2020 and December 2022, using a number of keywords, including extended reality, virtual reality, augmented reality, mixed reality, metaverse, virtual worlds, and immersive technologies. The team compiled the following information:

- Country
- Title of procurement
- Document number in TED (only for EU procurement)
- Link
- Name of contracting authority
- Type of contracting authority
- The main activity of the contracting authority
- The total value of the procurement
- Publication date
- Deadline of procurement procedure (if available)
- Use case of procurement (Research (e.g., Lab, research project), or production (no mention of research))

- What is procured (devices, software, services)
- Short description of what the procurement is buying
- Any other important information, e.g., who the tender was awarded to, the country they are based in, and their subcontractors.

Out of the information collected as outlined above, we added additional analytical categories to facilitate data analysis:

- Currency conversions from national currencies to EUR
- Standardised categories for use case of procurement:
 - Content production
 - Medical use
 - Entertainment and cultural or touristic experiences
 - Marketing, promotion and sales
 - Data visualisation and simulation
 - Research and development
 - Training and education
- Industrial ecosystems concerned by the procurement

In order to harvest information on the public procurement opportunities in the countries associated with Horizon Europe, we took the following two-step approach:

- Contacted public authorities responsible for public procurement in each country, and asked them for an overview of public procurement related to XR.
- If the authorities did not reply or did not provide information (which was the case for all of the countries), we looked at online public procurement websites and using machine translation tools searched manually for relevant public procurement entries (using the same approach as we adopted for the analysis of information available on TED).

The final database contains 404 entries in the EU Member States and 403 entries in HEAC.

Forward-looking analysis (Task 5)

During the desk research, XR virtual worlds (VW) available in the EU were mapped. To conduct the mapping, VWs were searched across the internet (e.g., through Google search, ChatGPT). Additionally, interview respondents were asked if they were aware of any virtual worlds. The focus mostly was primarily on the identification of VWs with industrial applications.

Once the VWs were identified, desk research was conducted for each of them to gather information about the following features:

- Date of creation and developer
- Approximate size of the community (overall and monthly active users)

- Type of users (businesses, citizens, and public sector)
- Domains where virtual worlds exist:
 - Industrial: if the VW can be applied in the industrial ecosystem. Industrial ecosystems are as follows: aerospace and defence, agri-food, construction, cultural and creative, digital, electronics, energy-intensive industries, energy-renewables, health, mobility – transport – automotive, proximity, social economy and civil security, retail, textile and fashion, and tourism.²⁵⁰
 - Education: if the VW can be used for educational purposes, such as medical students learning surgical procedures.
 - Entertainment: if the VW can be used for gaming or social applications.
- Business Model:
 - Main business partners
 - Investments in the VW
 - Accessibility (free, freemium, subscription-based, or other)
 - Commercialisation (VW purchase, advertising, goods, and services (selling goods and services through VW))
- Technologies used to run virtual worlds, including:
 - Payments, monetisation, and identity
 - Non-Fungible Tokens (NFTs) - Unique digital assets used to represent virtual goods and services in the VW, bought, sold, and traded on blockchain marketplaces.
 - Virtual land – Platforms, such as Decentraland, Somnium Space, and Cryptovoxels, allow users to buy and own virtual land in the VW, enabling the creation and monetisation of virtual experiences.
 - Payment gateways (PayPal, Stripe, Amazon Pay, Apple Pay, Bitcoin, other cryptocurrencies, Google Wallet, Skrill, Square, custom payment solutions)
 - Web 2/Web 3 (centralised -Web 2.0 or decentralised -Web3)
 - Devices, operating systems (OS), and accessories
 - Desktop computers – VW experiences can be accessed using standard desktop computers running operating systems, such as Windows, MacOS, or Linux
 - Mobile Devices – VW experiences can also be accessed using mobile devices, such as smartphones and tablets, running on operating systems, such as iOS and Android.

²⁵⁰ For more detailed description of each ecosystem see: https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

- Virtual Reality Headsets - VR headsets, such as Oculus Quest, Oculus Rift, HTC Vive, and PlayStation VR, can be used to immerse in the VW, and interact with it in a more realistic way.
 - Augmented Reality Devices - AR devices, such as Microsoft Hololens, Magic Leap, and Nreal Light, can be used to overlay virtual elements onto the real world.
 - Gaming Consoles - such as Xbox, PlayStation, and Nintendo Switch, can be used to access VW experiences, often with the use of specialised controllers and accessories.
 - Specialised Input Devices - Accessories such as hand controllers, gloves, and bodysuits can be used to track and control the user's movements within the VW.
- Infrastructure
 - Cloud computing - The VW requires large amounts of data storage and computing power, and cloud computing solutions, such as Amazon Web Services, Microsoft Azure, and Google Cloud, provide the necessary infrastructure and scalability to support it. There are several solutions:
 - Infrastructure as a Service (IaaS) allow users to rent virtualised computing resources, such as servers, storage, and networks, on-demand. This allows virtual world developers to easily scale their infrastructure, to meet the demands of a growing user base.
 - Platform as a Service (PaaS) offers a platform for developers to build, run, and manage their applications without having to worry about the underlying infrastructure. This can be useful for virtual world developers who want to focus on creating the virtual world itself, rather than managing the underlying servers and networks.
 - Software as a Service (SaaS) offers fully managed virtual worlds that users can access and interact with over the internet. This eliminates the need for virtual world developers to build and manage their own infrastructure, but also limits their ability to customise and control the virtual world.
 - Gaming as a Service (GaaS) offers cloud gaming solutions that allow users to stream and play high-end games without the need for high-end hardware. This can be used to run virtual worlds and other immersive experiences with high-end graphics and physics.
 - Edge computing - Enables data processing and storage closer to the end user, reducing latency, and improving the overall user experience.
 - Artificial intelligence - Used to improve the performance and functionality of virtual worlds' experiences. Examples include natural language processing, computer vision, and machine learning.

- Streaming technologies - Can be used to deliver VW experiences in real-time, allowing users to access them from anywhere with an internet connection.
 - Engine technology refers to the software systems that power virtual worlds, and provide the technical foundation for creating and operating virtual environments. This includes tools, libraries, and APIs for creating and running simulations, animations, and interactive experiences. Popular engine technologies include Unity and Unreal Engine.
- Evidence about quantitative and qualitative impacts
 - Short description of the VW.

This resulted in the database of the virtual worlds available in Europe and their key features and a general overview of what was collected in the database (see overview in Chapter 5).

As for mapping the emerging technologies, desk research has identified the following fields of emerging technologies relevant for XR and virtual worlds:

- Novel photonic technologies for displays
- Optics and sensing (incl. Haptic solutions)
- Connectivity (5G and 6G, Wi-Fi 6/7)
- Edge computing (edge-offloading)
- Cloud computing (AR/VR cloud, hybrid cloud)
- Advanced semiconductor chips (devices, efficiencies, capabilities)
- Graphene and metamaterials
- Blockchain
- AI

We built on the work done during the preparation of the project and continued desk research in these technology fields and any new unidentified technology fields. Desk research focused on the following main questions:

- What potential do different technologies have on the development of metaverse²⁵¹ and the adoption of XR?
- How can they help overcome the current challenges of metaverse development and XR adoption?

This resulted in the overview of emerging technologies, highlighting its potential for XR and virtual worlds.

²⁵¹ In the report we used term virtual worlds to be in line with the vocabulary used in Communication adopted by the European Commission on 11 July 2023, setting out a strategy focusing on Web 4.0 and virtual worlds.

Interviews

Interviews were carried out as part of landscape analysis (Task 2) and analysis of XR- and virtual world-related public initiatives in EU and HEAC (Task 4). The interviews allowed us to deepen the knowledge accumulated through desk research and fill in any remaining information gaps. In total 49 interviews were implemented involving stakeholders from 15 EU Member States and six non-EU countries.

In Annex 3, we provide a list of a total of 49 interviews from different organisations across industrial ecosystems. The interview questionnaire used for Task 2 interviews is presented in Annex 4. The questionnaire for Task 4 did not have a standard questionnaire as interviews were specific based on the information available about each public initiative analysed. The interviews followed a semi structured format, allowing stakeholders from different industrial ecosystems share inputs relevant for their respective expertise. For each interview a briefing of the study, its key objectives, and scope were provided to the interviewee. The set of questions acted as guidance for the main themes to be covered, however the specific questions were tailored to each specific industrial ecosystem/interviewee.

Events attendance

Events attendance allowed us to collect complementary information and latest insights not yet available in literature, to understand the dynamism of different XR hubs in Europe, to learn about the latest discussions and challenges faced by the industry first-hand, and also to engage with different stakeholders. The table below contains the list of 12 XR events that were attended during the implementation of the study.

Table 16. Overview of XR events attended during implementation

Event	Venue	Dates	Industrial ecosystems	Description
Microsoft HoloLens Healthcare Industry Forum	Online	07/06/2022	Healthcare	The goal of the HoloLens Industry Forum is to create a community of organizations excited by how HoloLens is being used to transform business and Industry.
Stereopsia	Brussels, Belgium	17/10/2022 19/10/2022	Horizontal	Stereopsia is one of the most prominent XR events in Europe. It gathers all type of stakeholders, such as entrepreneurs, investors, content creators, scientists, and audiences seeking the latest industry developments.
AWE EU 2022	Lisbon, Portugal	20/10/2022 21/10/2022	Horizontal	Biggest XR event & exhibition in Europe.
IIOT World Industrial Metaverse Day	Online	26/10/2022	Industrial, Metaverse	The event will bring together Industrial (IoT), AR, AI, and VR experts to share insights on Industrial Metaverse.
VRARA Healthcare Forum 2022	Online	28/10/2022	Healthcare	The forum aims to bring together the top thought-leaders and reflect on best practices, case studies, and ROI for immersive tech in healthcare. World's top hospitals, clinics, doctors, nurses, healthcare providers, and vendors will participate in this virtual forum.

Event	Venue	Dates	Industrial ecosystems	Description
GatherVerse Legal & Governance Summit	Online	02/11/2022	Horizontal	The Legal & Governance Summit will explore the legal and governance aspects of the virtual worlds with speakers from various fields and backgrounds. The summit aims to promote a humanity-first approach towards building the virtual world.
Xrcon	Online	17/11/2022 18/11/2022	Horizontal	The conference covers the topics of virtual and augmented reality, from the academic and tech world to the business world with relevant use cases. The XRcon is completely online and addressed to professionals, members of a start-ups or companies, students, or anyone interested in XR.
VR Days Europe/ Immersive Tech Week	Rotterdam, Netherlands	28/11/2022 02/12/2022	Horizontal	Immersive Tech Week is a festival where creativity, innovation, business, research, and art meet to explore the impact of immersive technologies on our planet, culture, and society.
Virtual World Symposium. GatherVerse Campus	Online	20/09/2022 21/09/2022	Horizontal	GatherVersi is a global ecosystem where communities gather, discuss, document, and share human-centred approaches to the virtual worlds.
Metaverse Safety Week	Online	10/12/2022 15/12/2022	Metaverse	The Metaverse Safety Week is an international community effort, led by the XR Safety Initiative, featuring industry leaders from around the world and spanning five days.
Art and the Metaverse: From Creation to Market	London, UK	14/02/2023	Creative & Cultural Industry	In this insights live webinar, the panel will investigate the biggest questions surrounding the growth of the virtual worlds' art world. The potential discussion will surround the process of making and selling art in the virtual worlds, the growth of AI generators, and the value of art as a commodity in the digital economy.
Virtuality 2023	Paris, France	16/03/2023 17/03/2023	Horizontal, Metaverse	Professional trade show dedicated to WEB3 and Metaverse.

Source: Authors' own elaboration.

Case studies

Case studies of the eight selected public initiatives in third countries compared public initiatives, and assessed their potential impact for the XR industry at a global-level, and in particular for the EU strategic autonomy. Initiatives from the following countries were analysed: United Kingdom, South Korea, US, UAE, Australia, Argentina, South Africa, and Brazil. Please see Annex 6 for full case studies and Table 13 for an overview of the selected initiatives.

In order to select the 8 most relevant initiatives for analysis, we used the following selection criteria:

- Key actions foreseen
- Foreseen funding

- High expected impact
- The largest potential for scale-up (as described by the authorities themselves)
- Geographical balance (at least one initiative per continent)

Each case study relied on desk research and followed a structured approach. The structure of each case study included the following components:

- **Overview:** Basic information about the initiative: geographic area, country, and website (if available).
- **Objectives and Scope:** Description of the initiative's objectives, scope, actors involved in the implementation, timeline, and details of the budget and funding available.
- **Assessment of the impact of the initiative:** Assessment of the initiative's impact, considering factors, such as successful implementation, potential for scaling up, and addressing important barriers, gaps, ecosystems, or technologies of strategic importance to the EU. The goal is to determine if the initiative can serve as a good example for addressing similar challenges in the EU.

Additionally, one to two interviews with the public authorities responsible for the public initiative were envisioned for each case study. As of delivery of this report:

- An interview with Digital Catapult (UK) has been conducted on April 3, 2023.
- An interview with Electric South (South Africa) has been conducted on April 14, 2023.
- An interview with Queensland XR Hub (Australia) has been conducted on May 3, 2023.
- Written input was obtained from Metaverse Seoul (South Korea) on May 3, 2023,
- Representatives from the remaining four case studies were all invited for an interview, but the study team did not receive a response.

After preparing the first draft of the case study, we sent it to key stakeholders for verification of factual data, whenever they requested to see the case study. This ensured that factual data on the initiative is accurate and complete. After the cases were drafted, cross-case analysis was the basis for the assessment of the impact that they may have at a global-level for the XR industry, and, in particular, for the EU strategic autonomy.

Delphi survey

Delphi survey helped to assess the role XR technologies will play in the EU industry by the end of the current decade and identify the lines of research and emerging paradigms with the greatest potential to break through current technology limitations and accelerate the wider uptake of XR.

The survey was conducted in two rounds with the same group of people. There were 109 responses to the first round of the Delphi survey. The second round Delphi survey was filled by 23 respondents. During the first round XR experts were asked to predict how the XR market can change by 2030, evaluate the likelihood of opportunities and challenges, and rate emerging technologies. During the second round of the Delphi survey, the experts (respondents) received the results from the previous round to allow them to learn from one

another, and build consensus among themselves. It was conducted anonymously to prevent the discussion from being dominated by one individual and to allow each expert to give their honest opinion. The Delphi survey was carried out in four stages:

- *Preparatory stage* involved the development of the questionnaire, identification of experts, and piloting of the questionnaire. The first round of the questionnaire was piloted with three XR experts and five thematic experts. The questionnaires focused on two different parts based on the research questions:
 - Role of the virtual worlds²⁵² and XR in the future of the EU industry. We identified challenges and opportunities that the virtual worlds, and the wider take-up of XR technologies, could offer to the EU industry. Respondents were asked to rank the likelihood of these opportunities materialising, and to select sectors and application domains where the impact of these opportunities would be the largest.
 - Emerging technologies with the potential to have an impact on the development of the virtual worlds and wider adoption of XR. This section listed the identified technologies and asked respondents to rate their importance in the development of virtual worlds and increasing adoption of XR, the likelihood that they will overcome different challenges of virtual worlds' development and XR adoption, and the importance of research and innovation activities to exploit their potential in relation to virtual worlds and XR.
- *First round of Delphi survey* was managed through Alchemer™. A total of 617 XR and virtual worlds experts were invited to fill in the survey via email. This was followed by two reminders. In addition, the invitation was broadly shared on social media platforms (LinkedIn, Facebook), and disseminated via XR associations. There were 109 responses to the first round of the Delphi survey, out of which 52 respondents fully filled out the questionnaire and 57 partially filled it (meaning that portion was left blank). Answers to the survey (see Annex 3) showed the level of consensus among the surveyed experts, the most popular and the most extreme (rare) answers.
- *Second round of Delphi survey.* There were 77 XR experts, who agreed to be contacted for the second round, and were invited to fill in the second round of the Delphi survey. Along with the questions, experts received a short summary of the results from the previous round. During the second round, experts were asked to assess the results of the first round and evaluate the likelihood of answers received in open-ended question text boxes. In this way, the stability of opinions was measured. In addition to the invitation, we sent two reminder emails. The second round Delphi survey was filled by 23 XR respondents (16 complete and 7 partial answers).
- *Results* from both rounds of the Delphi survey were collected and transformed into a coherent narrative that outlines experts' views on the role of XR in the future of the EU industry and the emerging technologies and their potential impact on XR.

Online workshops

The study was supplemented by two online workshops. One was held on June 15, 2023, and dedicated to validating the preliminary findings of the study and discuss the alternatives and suggestions for policy recommendations. The summary of workshop discussions is

²⁵² The survey questionnaire used term metaverse, but the report was revised to be in line with the vocabulary used in Communication adopted by the European Commission on 11 July 2023, setting out a strategy focusing on Web 4.0 and virtual worlds.

presented in Annex 7. The second workshop is scheduled for September 19, and will be dedicated to presenting and discussing the final study results. The table below briefly outlines the concept of the first workshop.

Table 17. Concept of the workshop

Aim	To discuss, validate, and gather ideas for study recommendations.
Duration	2.5 hours, which is optimal duration to keep the participants' attention, and ensure their high engagement throughout the whole event.
Organisation	• The workshop was carried out online, via MS Teams. • The workshop was moderated by experienced project team members (Audronė Sadauskaitė, Jonas Antanavičius, Alexandros Vigkos) • Visionary Analytics technicians were responsible for solving any technical issues. • The event were summarised in the form of the minutes (see Annex 7).
Agenda	(1) Introduction to the discussion: (45 min.) Introductory word. Objectives of the discussion. Presentation of the study results. (2) Two parallel discussions (moderated by project team members): (~1 h) Discussion on the findings. Discussion about the initial recommendations and the potential suggestions for recommendations. (3) Wrap-up discussion: key conclusions and next steps (30 min).
Participants	• Workshop participants covered the following areas of expertise: academics, technologists, developers/marketers, investors in XR tech, owners/company managers, industry representatives, policy makers. People that we kept in touch during the project (Delphi survey, interview respondents) are one of the main sources for identifying workshop participants. • The first workshop included 25 participants. The parallel discussions were organised in two separate groups of 12-14 participants. • Participants were asked for consent to participate in the research.

Source: Authors' own elaboration.

Annex 2: List of sources for desk research

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[XR and its potential for Europe \(2021\)](#)
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Market reports:

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[Extended Reality \(XR\) Market – Growth, Trends, Covid-19 Impact, and Forecast \(2022 – 2027\)](#)

[The European market potential for VR and AR services \(2021\)](#)

[Global Extended Reality \(XR\) Market Report, History and Forecast 2016 – 2027 \(2021\)](#)

[Value creation in the metaverse. The real business of the virtual world \(2022\)](#)

[Report Ocean: Europe Extended Reality Market Europe – Industry Dynamics, Market Size and Opportunity Forecast to 2030 \(2022\)](#)

[Virtual Reality Market Size, Share & Trends Analysis Report \(2021\)](#)

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[5G networks towards smart and sustainable cities: A review of recent developments, applications and future perspectives \(2021\)](#)

[Advanced Study of Optical Imaging Systems for Virtual Reality Head-Mounted Displays \(2023\)](#)

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[Application of virtual and augmented reality in automotive \(2020\)](#)

[Artificial intelligence for the metaverse: A survey \(2022\)](#)

[A Review of Extended Reality \(XR\) Technologies for Manufacturing Training \(2020\)](#)

[A review towards AI empowered 6G communication requirements, applications, and technologies in mobile edge computing \(2022\)](#)

[A survey of blockchain from the perspectives of applications, challenges, and opportunities \(2019\)](#)

[A Systematic Literature Review on Extended Reality: Virtual, Augmented and Mixed Reality in Working Life \(2021\)](#)

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[Extended Reality \(XR\) Remote Research: a Survey of Drawbacks and Opportunities \(2021\)](#)

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- [Augmentor](#)
- [Virtualisation](#)

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- [Electric Africa](#)
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- [Workshops](#)

- [World Heritage Futures Lab](#)

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[Metahype](#)

[Ministry of Science, Technology and Innovation \(Brazil\)](#)

[Mona](#)

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[National Council for Scientific and Technological Development \(Brazil\)](#)

[Nvidia](#)

[Openwind](#)

[Party - Virtual Parties & Corporate Metaverse Events Platform](#)

[Pavia](#)

[PICO 4](#)

[Queensland XR Hub](#)

- [Aerospace Xelerated Pitch Challenge - Awards & Networking](#)
- [Aerospace Xelerated Pitch Challenge](#)
- [Events](#)
- [Tenders](#)

[RAEscolas](#)

[Remo - Virtual events platform](#)

[Screen Queensland](#)

[Sensorium - We bring you connections & experiences out of this world](#)

Seoul Metropolitan Government

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- [Mid- to long-term basic plan](#)
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Annex 3: List of interview respondents

For the purposes of the landscape analysis, we conducted a total of 49 interviews across industrial ecosystems. We also to the extent possible reached out to a diverse group of interviewees in terms of types of stakeholders (users/providers of XR solutions), geographical location of their organisation (amongst EU Member States), and representing different industrial ecosystems (a minimum of two representatives per ecosystem were interviewed). The full list of interviewees is hereby presented.

Table 18. List of interview respondents

Name, Surname	Position/ role in the organisation	Organisation	Country
David Nahon	Immersive experience director/ Secretary General	Dassault Systemes /CNXR	FR
Pat O'Connor	Managing director	AIVRSimulation	IE
Maarten Hermans	Simulator Developer	E-flight academy	NL
Jeroen Van Der Wel	Head Thales XR labs	Thales	NL
Jorgen Rimmelg	CEO	XMReality	SE
Ivan Đurić	XR LAB coordinator	Leibniz Institute of Agricultural Development in Transition Economies	DE
Siwart Mackintosh	Business Unit Manager & Head of Partnerships	Infinity Labs	NL
Stella Ntavara	Project manager for cultural projects, Events & Production coordinator	Copenhagen International Documentary Film Festival	DK
Gonzalo Carrión	COO	El Ranchito	ES
Gabriella Chihan Stanley	CEO	Vrisch	AT
Christina Chrysanthopoulou	Art Director	ViRA	EL
Guido D'Arezzo	Events Operations Manager	AnotheReality	IT
Ricard Gras	Founder	Captic	DE
Marcin Klimek	CEO	ExplodedView	PL
Daniel Gremli	Founder	Bamdara	CH
Eloi Girard	Founder	END Entertainment	BE
Peter Verstraeten	CEO	Proceedix	BE
Vasilapostolos Ouranis	Co-founder	Magos	EL
Lars Riedemann	Physician -Scientist	Heidelberg University Hospital	DE

Name, Surname	Position/ role in the organisation	Organisation	Country
Remco Hoogendijk	Innovation Manager	Sint Maartenskliniek	NL
Nicolas Van de Kerkhof	Business Creation lead	EIT Health	DE
Roderick van Beek	Business Developer Healthcare	SyncVR Medical	NL
Jaap Gielik	CEO	Windsor	NL
Eric Fassbender	Founder	Atmospheares	DE
Sonke Kirchhof	Founder	InVR Space	DE
Jan Kamphuis	Co-owner	Building Virtuality	NL
Sara Stankovic	BIM Specialist	Goldbeck	DE
Duzan Doepel	Co-funder	Doepel Strijkers	NL
Kayvan Mirza	CEO	Optinvent	FR
Stan Larroque	CEO	Lynx	FR
Kim Branner	Department of Wind and Energy Systems & ReliaBlade Project Coordinator	DTU (Project ReliaBlade)	DK
Kim Bleshøj Nielsen	Managing Director, Partner	Intertisement	DK
Lene Thirup	Business Development Director	Kanda	DK
Britta Schaffmeister	CEO	Dutch Marine Energy Centre	NL
Mikko Luukkonen	Solution sales	Softability OY	FI
Franco Trapasso	Head of Plant Project Office	Festo	DE
Jan Pflueger	Audi AG	XR Method Development - Audi Design	DE
Stefan Domdey	VP of sales	Threedly	DE
Amon Shalev	CEO	Virtuality.fashion	DE/ISR
Annita Apostolaki	Digital Marketing Manager	Artsteps	GR
David G.	Founder	Krill Audio	ES
Mads Dambo	Founder and lead producer	Makropol	DK
Dr.Oliver Schreer	Head of Research Group	Fraunhofer Institute for Telecommunications	DE

Name, Surname	Position/ role in the organisation	Organisation	Country
Thomas De Bruyne	Xperience Lab Lead	Deloitte	CZ
Richard Ballaux	VR Product Manager	OneBonsai	BE
Anonymous	Anonymous	Digital Catapult	UK
Karen Sanders	CEO	Queensland XR Hub	Australia
Antoinette Engel	Producer	Electric South	South Africa
Anonymous	Anonymous	Metaverse Seoul	South Korea

Source: Authors' own elaboration.

Annex 4: Interview questionnaire

The interviews will follow a semi structured format, allowing stakeholders from different industrial ecosystems share inputs relevant for their respective expertise. For each interview a briefing of the study, its key objectives and scope will be provided to the interviewee. The following set of questions will act as guidance for the main themes to be covered, however the specific questions may be tailored to each specific industrial ecosystem/interviewee.

Part 1: Introductory questions

- About the interviewee:
 - Full name:
 - Organisation:
 - Role:
- About the organisation:
 - Please briefly introduce your organisation's activities in relation to XR/Metaverse.
 - What Industrial Ecosystem(s) does your organisation operate? [select from list]

Part 2: Characteristics of the Industrial Ecosystem [Each interview will focus on one industrial ecosystem based on each organisation's expertise.]

- What domains (types) of applications are you offering in the specific ecosystem?
 - What application domains are higher on demand in the industrial ecosystem in question?
 - What are the main benefits for the user of each application domain? Have you recorded any quantifiable benefits?
 - Could you share any specific examples of unique applications/use cases and their benefits for the user?
 - What are the main challenges associated with the development of each application domain?
 - What are the main challenges associated with the use of each application domain?
- To what extent has the XR deployment in your industrial ecosystem reached its maximum potential? How would you compare the XR deployment in the industrial ecosystem compared to others (i.e., would you say it is ahead or lagging)?
- Are there any specific characteristics of the 'typical' adopter of XR solutions? E.g., size of company, specific segment of the industrial ecosystem, level of digitalisation, etc.
- Are there any segments of the industrial ecosystems that are more/less involved in the adoption of XR solutions?

Part 3: Expectations and conditions for broader deployment

- Expectations
 - Are there any applications you are not offering yet, but expect to offer in the next two years?
 - What domain of application is the most promising in terms of potential disruptiveness?
 - What domain of application is the most promising in terms of potential market demand?
- Conditions
 - What are the main current or anticipated challenges in relation to the broader deployment of XR solutions in the Industrial Ecosystem?
 - What technological advancements are key for the broader deployment of XR solutions in the Industrial Ecosystem?
 - Are there any differences/unique conditions of this industrial ecosystem?

Part 4: Awareness on the ecosystem and public support initiatives

- Are you aware of any XR associations in the specific industrial ecosystem, in your country, in the EU in general, and/or Horizon Europe associated countries?
- Are you aware of any funding opportunities available in your country, in the EU in general, and/or Horizon Europe associated countries?
- Are you aware of any (databases of) national or regional public initiatives (e.g., policy measures, actions, plans, their corresponding instruments, tools) supporting XR development or deployment in the EU, Horizon Europe associated countries, and/or in third countries/worldwide?
 - If yes, could you provide some information on those: what authority or organisation is behind the initiative? Any link or document where we can find more information?
 - If yes, do you have any observations to share on the effectiveness of the initiative?
 - *[If the respondent mentioned an initiative in a third country] Are you aware of additional information regarding this initiative?*
 - *If yes, could you please elaborate on the potential impact that this initiative may have at a global-level for the XR industry, and, in particular, for the EU strategic autonomy?*
- Are there any public initiatives that are needed for the further or optimal deployment of XR in the industrial ecosystem in question?
- Is there any other feedback or information you would like to share?

Annex 5: Delphi Survey questionnaire

ROUND 1

Introduction

Thank you for taking part in this Delphi survey. This survey aims to estimate the role XR technologies will play in the EU industry by the end of the current decade, identify lines of research and emerging paradigms that might have an impact on XR, and estimate the potential of them on XR and in addressing current challenges of XR adoption. We are in particular interested to know your views on:

- **The role of the metaverse and XR technologies** in the EU industry by 2030, and
- The potential and **impact of emerging technologies** on XR.

Extended Reality (XR) – is the umbrella term used for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), as well as future realities immersive technologies might create. XR involves various approaches to creating or expanding the environment experienced through multiple senses (primarily visual), and is also closely related to new approaches to interaction with computer systems, such as gloves or suits.

Metaverse is a universe of virtual worlds, among which the user can move freely and also have the ability to create and modify the environment.²⁵³ The metaverse blends real and virtual worlds. From one side, virtual world imitates the real world providing digital experience of real life. From the other side, real life is enhanced by the features of digital world (e.g., through AR).

About the Delphi survey method: Delphi survey will have two rounds with the same group of experts. After the first round, the information collected will be summarised and shared with you before the second round. The second round will dive deeper into the sectoral application of technologies and their potential to overcome the current challenges of XR adoption. Thus, your participation in both rounds of the survey is essential.

The study will assist the Commission in designing lines of strategy and preparing actions to contribute to the strengthening of the XR industry, and to incentivise industrial digitalisation through the uptake of XR technologies, in a competitive, secure, and ethical environment. The study is performed by [Visionary Analytics](#), [Ecorys](#), and [IDEA Consult](#). It is carried out at the request of the European Commission, DG Connect. Please find the support letter [here](#).

The survey should take around 15 minutes. If you have any issues/ questions, please contact aurinta@visionary.it. Thank you.

Data Privacy and Informed Consent Information

Your personal data will be processed in line with Regulation (EU) 2018/1725 of the European Parliament and of the Council of 23 October 2018 on the protection of natural persons regarding the processing of personal data by the Union institutions, bodies, offices, and agencies, and on the free movement of such data. Your data will only be processed by Visionary Analytics employees entrusted with the implementation of the project.

²⁵³ Fabio Moio "The Metaverse: Don't Confuse It With Virtual Reality"
<https://www.forbes.com/sites/forbestechcouncil/2022/08/11/the-metaverse-dont-confuse-it-with-virtual-reality/?sh=3aa792ec2257>

Your answers will be anonymised, aggregated, and published as part of the study report. None of your personal details (e.g., e-mail address) will be published or disclosed. The full information regarding data protection is provided in the privacy statement that can be found [here](#).

Q0-1. Please select*

- ☐ I agree to my data being processed as outlined in the privacy statement

Q0-2. Please select

- ☐ I agree to be contacted for the second round of the Delphi survey. If yes, please enter your email
-

Part 1: General questions

Q1-1. You are filling in this questionnaire primarily as: (please select all applicable answers)

- ☐ XR application company
- ☐ XR device company
- ☐ XR researcher/academic/consultant
- ☐ XR association representative
- ☐ An expert of technology relevant for technology related to Metaverse (i.e., blockchain, AI, IoT, 5G/6G)
- ☐ XR end user
- ☐ Other (please write in) _____

Q1-2. Please select XR-relevant technological fields you have knowledge in (if any). Select all applicable options.

- ☐ XR software development
- ☐ XR content generation
- ☐ Dedicated applications of XR (e.g., in engineering, training, quality assessment)
- ☐ Novel photonic technologies for displays
- ☐ Optics and sensing (incl. Haptic and tactile solutions)
- ☐ Connectivity (5G and 6G, Wi-Fi 6/7)
- ☐ Edge computing (edge-offloading)
- ☐ Cloud computing (AR/VR cloud, hybrid cloud, ML)
- ☐ Artificial intelligence
- ☐ Advanced semiconductor chips
- ☐ Graphene and metamaterials
- ☐ Blockchain
- ☐ None of the above
- ☐ Other (please write in) _____

Q1-3. What sectors you are active in? Please select all applicable answers

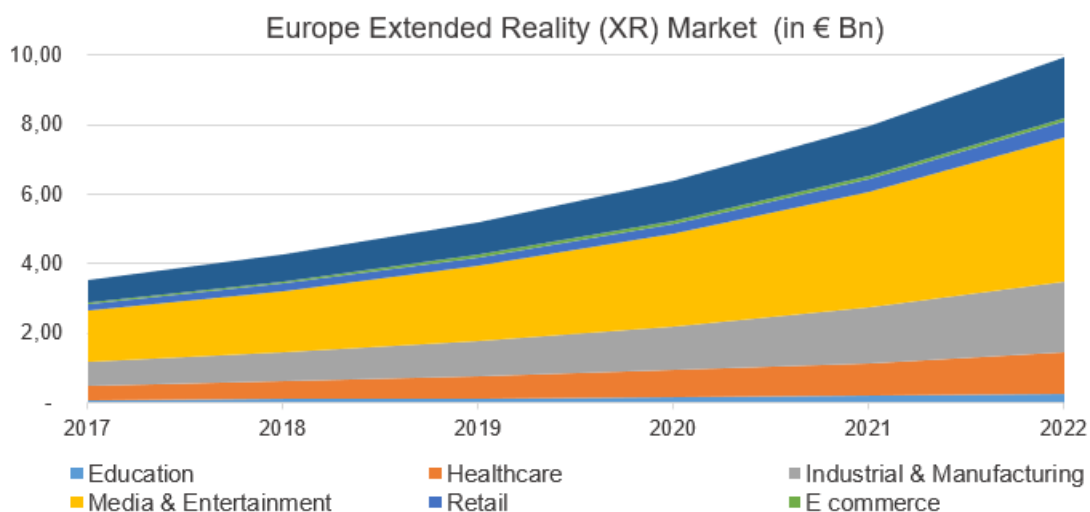
Detailed information about each sector can be found in Annex 3 of this document (pages 75-181): https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

- ☐ aerospace and defence
- ☐ agri-food
- ☐ construction

- ☐ cultural and creative industries (incl. entertainment, media, and gaming)
- ☐ digital
- ☐ education
- ☐ electronics
- ☐ energy-intensive industries
- ☐ energy-renewables
- ☐ health
- ☐ mobility – transport – automotive
- ☐ proximity, social economy, and civil security
- ☐ retail
- ☐ textile and fashion
- ☐ tourism

Part 2: The role of metaverse and XR technologies in the EU industry by 2030

A recent study on the economic position and potential of XR in Europe shows that the market value of the European XR industry is expected to reach between €35 – €65 billion by 2025. It is expected to generate €20 – €40 billion gross added value, and directly create employment for up to 860,000 people by 2025 (Ecorys. 2021).



Source: Report Ocean: Europe Extended Reality Market Europe - Industry Dynamics, Market Size and Opportunity Forecast to 2030 (March 2022).

Q2-1. In your opinion, how might the situation change by 2030?

- The XR market will exponentially grow (40%+)
- The XR market will continue to grow at the same pace as the past 5 years (20-40%)
- The XR market growth will slow down (0-20%)
- The XR market will shrink (negative growth)
- Other (please write in)

Q2-2 In your opinion, how might the situation change by 2030 in different sectors? (only sectors under selected Q1-3 shown)

	Exponentially grow (40%+)	Grow at the same pace (20- 40%)	Slow growth (0- 20%)	Negative growth	Do not know
aerospace and defence					
agri-food					
construction					
cultural and creative industries					
digital					
electronics					
energy-intensive industries					
energy-renewables					
health					
mobility – transport – automotive					
proximity, social economy, and civil security					
retail					
textile and fashion					
tourism					

Q2-3. Please provide arguments. Please refer to examples if possible that support your claim

Opportunities

Q2-3. Please rate the likelihood that the following opportunities created by metaverse and wider take-up of XR technologies could materialise by 2030.

	1 – not likely	2 – somewhat likely	3 – moderately likely	4 – likely	5 – very much likely	Do not know/ cannot answer
Demand: increasing demand (and uptake of social XR applications) in the consumer market (improved and cheaper hardware, popular applications, higher connectivity)						
Virtual commerce: metaverse will become a new platform for selling, trading goods and services						
Education and training: XR will be incorporated as a standard						

practice in job related training/educational programmes (e.g., surgery training, distributed training environments, scalable to any size of auditorium)						
New work: Virtual environments will be commonly used for remote work interactions and will improve work processes						
Efficiency gains: organisations employing XR will cut costs (e.g., less recalls, less travel, less physical prototypes, faster product development), and offer better-quality products and services (e.g., faster reaction time to mistakes, better creativity, more prototypes developed/tested)						
Employment: XR will disrupt employment for technical and creative occupations						
Connectivity: 6G will be the ultimate enabler for advanced, currently limited XR applications, lightweight XR glasses, HPC at our fingertips						
Research and development: XR will allow experimentation and exploration across all fields						

Q2-4. Please list any other opportunities that metaverse and wider take-up of XR technologies could offer to the EU industry and the EU economic competitiveness, by 2030.

Challenges

Q2-7. Please rate the likelihood that the following challenges could hinder the successful adoption of XR technologies in the EU industry

	1 – not likely	2 – somewhat likely	3 – moderately likely	4 – likely	5 – very much likely	Do not know/ cannot answer
Technical challenges (computing performance, battery life, devices not human centric, poor resolution of image, 5G SA, and 6G deployment, etc.)						
Infrastructure challenges (infrastructure shortcomings, bad integration (into company						

processes, legacy IT, lack of standards, bad interoperability)						
Market-related challenges (fragmented XR market, lack of awareness about XR, costly XR implementation solutions, difficulties in commercialising, etc.)						
Legal challenges (data protection, access to personal information, protection of intellectual property, etc.)						
Ethical challenges (not inclusive, may cause lasting emotional, and psychological impact, ability to collect sensitive data such as face and eyes movement)						
User acceptance challenges (awareness and ethical considerations, conservative attitude/no willingness to change)						
Financial challenges (relates to the lack of investments)						
Content creation (challenges with the lack of content creators and content in general)						

Q2-8. Please list any other challenges that could prevent the successful adoption of XR technologies in the EU industry.

Q2-11. Do you have any other thoughts or comments on the role of XR technologies in the EU industry that you would like to share?

Part 3: The potential and impact of emerging technologies on XR

Q3-1. Please rate the importance of the following emerging technologies fields relating to the development of XR hardware.

	1 – not important at all	2 – slightly important	3 – moderately important	4 – important	5 – very important	Do not know/ cannot answer
Novel photonic technologies for displays						
Optics and sensing (incl. Haptic solutions)						

Connectivity (5G and 6G, Wi-Fi 6/7)						
Edge computing (edge-offloading)						
Cloud computing (AR/VR cloud, hybrid cloud)						
Artificial Intelligence						
Advanced semiconductor chips						
Graphene and metamaterials						
Blockchain						

Q3-2. Please rate the importance of the following emerging technologies fields relating to the development of applications of XR (e.g., metaverse) .

	1 – not important at all	2 – slightly important	3 – moderately important	4 – important	5 – very important	Do not know/ cannot answer
Novel photonic technologies for displays						
Optics and sensing (incl. Haptic solutions)						
Connectivity (5G and 6G, Wi-Fi 6/7)						
Edge computing (edge-offloading)						
Cloud computing (AR/VR cloud, hybrid cloud)						
Artificial Intelligence						
Advanced semiconductor chips						
Graphene and metamaterials						
Blockchain						

Q3-3. Please list any other technologies or technology fields that could break through current technology limitations and accelerate the development of metaverse and wider uptake of XR. Provide arguments.

Q3-4. Do you have any other thoughts or comments on potential and impact of emerging technologies on XR?**Thank you**

Your participation in this survey will provide valuable insights that will help shape the future of XR in the EU industry. Thank you for your time and expertise.

ROUND 2

Introduction

Thank you for taking part in the second round of this Delphi survey. The results of the first round will be presented next to the relevant question. When writing the findings and designing second round of Delphi survey, we tried to include as much of your original wording as possible. This was to avoid changing the context of your feedback. During instances where there were differing views, we tried to ensure that we presented all perspectives.

Scope of the survey

This survey aims to estimate the role XR technologies will play in the EU industry by the end of the current decade, identify lines of research and emerging paradigms that might have an impact on XR, and estimate the potential of them on XR and in addressing current challenges of XR adoption. As XR technologies are at the core of building virtual worlds, such as the metaverse, the survey will touch upon this topic, as well.

This survey will be used for the purposes of conducting a study on behalf of the European Commission. Please find the support letter [here](#).

The study will assist the Commission in designing lines of strategy and preparing actions to contribute to the strengthening of the XR industry, and to incentivise industrial digitalisation through the uptake of XR technologies, in a competitive, secure, and ethical environment. The study is performed by [Visionary Analytics](#) , [Ecorys](#), and [IDEA Consult](#).

Terminology

Extended Reality (XR) – is the umbrella term used for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), as well as future realities immersive technologies might create. XR involves various approaches to creating or expanding the environment experienced through multiple senses (primarily visual), and is also closely related to new approaches to interaction with computer systems such as gloves or suits.

Metaverse is a universe of virtual worlds among which the user can move freely and also have the ability to create and modify the environment.²⁵⁴ The metaverse blends real and virtual worlds. From one side, virtual world imitates the real world providing digital experience of real life. From the other side, real life is enhanced by the features of digital world (e.g., through AR).

In practice:

We are in particular interested to know your views on:

- **The role of the XR technologies and the metaverse** in the EU industry by 2030, and
- The potential and **impact of emerging technologies** on XR.

The survey should take around 15 minutes. If you have any issues/ questions, please contact aurinta@visionary.it. Thank you.

Data Privacy and Informed Consent Information

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Your answers will be anonymised, aggregated, and published as part of the study report. None of your personal details (e.g., e-mail address) will be published or disclosed. The full information regarding data protection is provided in the privacy statement that can be found [here](#).

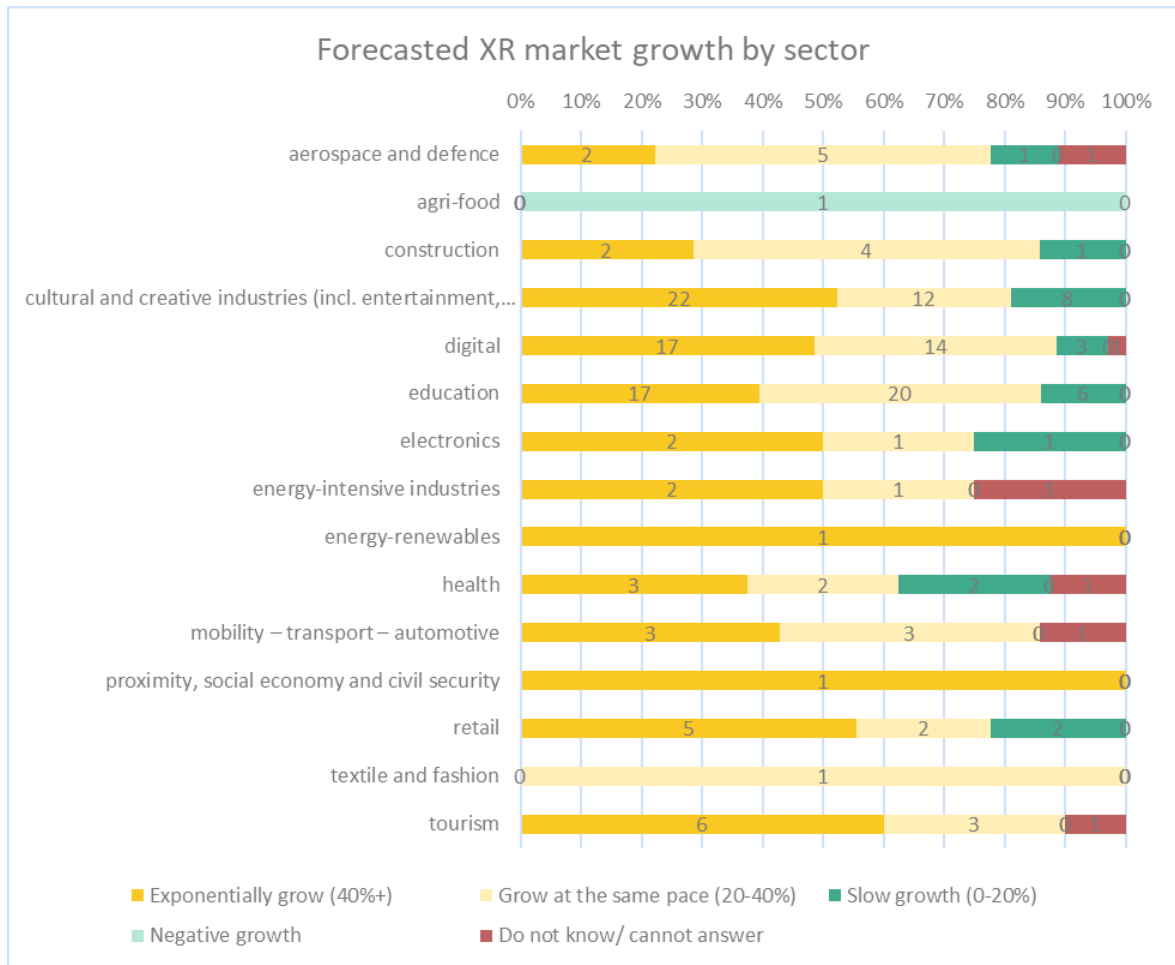
Q0-1. Please select*

- ☐ I agree to my data being proceed as outlined in the privacy statement

Part 1: The role of the XR technologies and the metaverse in the EU industry by 2030

Based on the first round of the Delphi survey, experts think that until 2030 XR market will grow on the same pace (20-40%) or exponentially (40%+).

²⁵⁴ Fabio Moio "The Metaverse: Don't Confuse It With Virtual Reality"
<https://www.forbes.com/sites/forbestechcouncil/2022/08/11/the-metaverse-dont-confuse-it-with-virtual-reality/?sh=3aa792ec2257>



Note: N=78

Source: Delphi survey, round 1, 2023.

Q1-1. To what extent do you agree with this finding?

- ☐ Strongly agree
☐ Agree
☐ Disagree
☐ Strongly disagree
☐ Do not know/ cannot answer

Q1-2. Please elaborate on your answer

Q1-3. To what extent do you agree with the following statements?

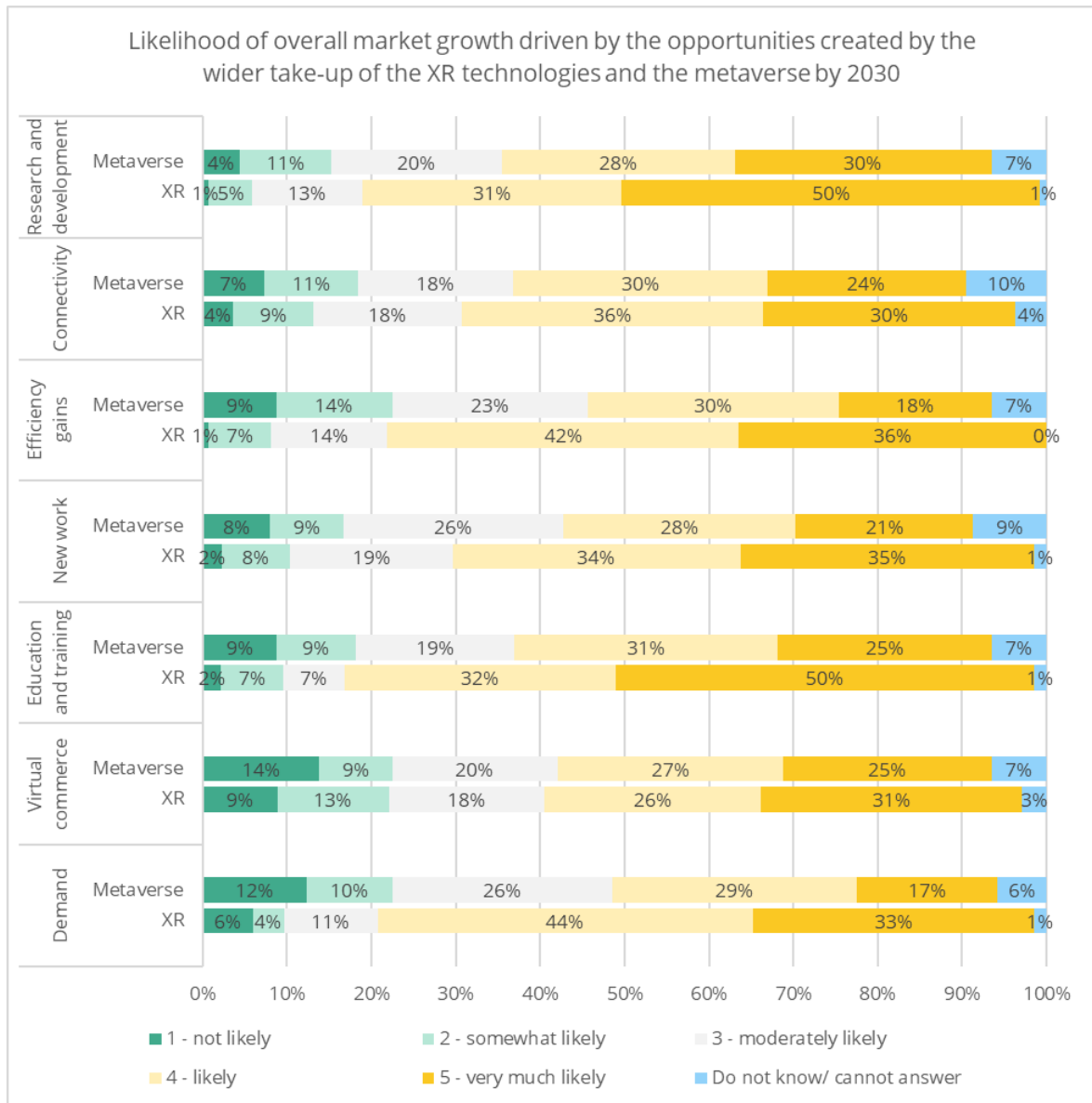
The following statements were collected through open questions in the first round of the Delphi survey. Thus, we would like to ask your views on it.

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
We will have yet another exponential increase, until 2030, as we will witness the launch of equipment that is under development					
Europe has difficulty keeping up with other continents due to too high load of					

regulation hampering innovation on a small and medium scale					
The costs of good XR Hardware will go down so there will be overall growth in most/all sectors					
Mass adoption of XR will occur as soon as the visuals meet expectations (hardware capabilities to show high-quality visuals)					
All the industries mentioned in the figure above will face existential threats, if they do not innovate and adopt these new technologies that consumers will demand more and more					
Sectors, in which there is more money (e.g., entertainment, media, gaming) are getting quick wins, while the ones with less money and retail (e.g., education) is a slow mover					

Opportunities

In the first round of the Delphi survey, we tried to see what the likelihood of growth driven by the (1) wider take-up of XR technologies, and (2) metaverse by 2030 is. Even though we looked at this question through the angle of different sectors, the same tendency in all sectors was noticed that the likelihood is higher for the opportunities when it is driven by wider take-up of XR technologies than metaverse.



Note: Total N=61

Source: Delphi survey, round 1, 2023.

Q1-4. To what extent do you agree or disagree that?

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
XR will drive market growth more than wider take-up of the metaverse					
This tendency (see statement above) is prominent in all sectors covered in the figure above					

Q1-5. Please elaborate on your answers

Q1-6. For the below-listed fields, please rate the likelihood of growth driven by the opportunities created by the wider take-up of XR technologies and the metaverse by 2030.

The following statements were collected through open questions in the first round of the Delphi survey. Thus, we would like to ask your views on it.

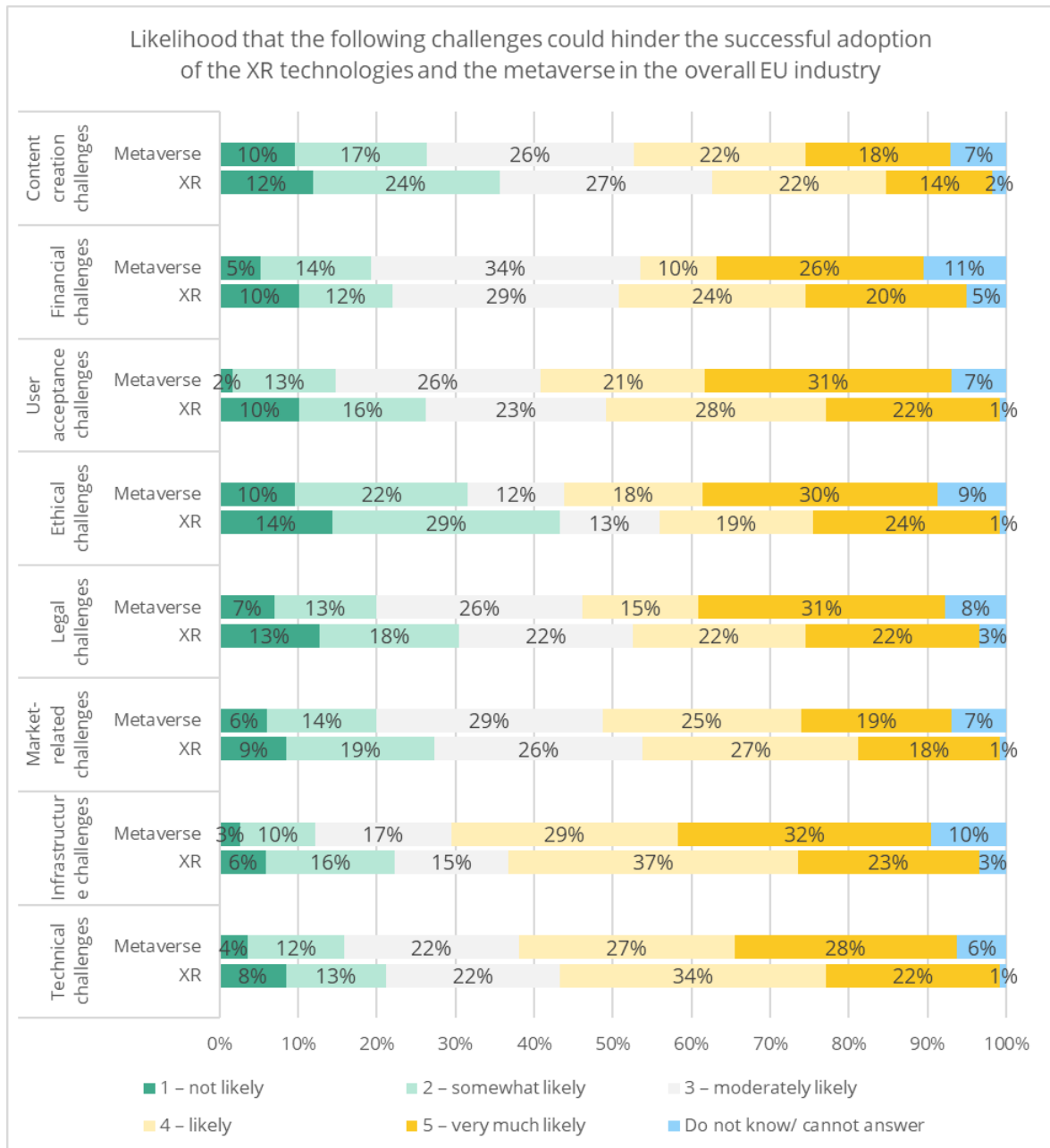
	Not likely	Somewhat likely	Moderately likely	Likely	Very much likely
Decrease in material waste, due to less errors					
Decrease in risk to assets and employees					
Increase in productivity and employee flexibility/versatility					
Green, collaborative Europe (less travelling, but more social interaction, open, decentralised network of virtual spaces including universities, social meeting spaces, communities)					
A shift in education (shift from digital to the virtual era) in terms of content and way of teaching					
Entrepreneurship growth, start-up funding growth					
New forms of remote work resulting in reduced brain drain (from one EU country to another EU country)					
New forms of remote work resulting in reduced brain drain (from EU to outside of EU)					

Q1-7. Please elaborate on your answer

--

Challenges

The figure below illustrates results obtained from the first round of Delphi survey. Survey revealed that according to the experts, below-listed challenges are more likely to hinder successful adoption of XR, than metaverse (except for content creation and financial challenges). In addition, the most prominent challenges indicated were technological and infrastructure challenges. Content creation and ethical challenges, on the other hand, were among the ones that might hinder the successful adoption of XR or metaverse less likely.



Note: N=52

Source: Delphi survey, round 1, 2023.

Q1-8. To what extent do you agree or disagree that?

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
Listed challenges are more likely to hinder successful adoption of XR, than metaverse					
The most prominent challenges are technological and infrastructure challenges					
Content creation and ethical challenges are among the ones that are less likely to hinder the successful adoption of XR or metaverse					

Q1-9. Please elaborate on your answers. If you have any comments on findings, please note them here.

--

Q1-10. For the below-listed fields, please rate the likelihood that the following challenges could hinder the successful adoption of the XR technologies and the metaverse in the EU industry.

The following statements were collected through open questions in the first round of the Delphi survey. Thus, we would like to ask your views on it.

	Not likely	Somewhat likely	Moderately likely	Likely	Very much likely
Fake content and avatar identity thefts					
Most people are still unaware of what is possible with XR technologies or have the wrong ideas (lack of education and understanding)					
Geopolitical/digital autonomy & sovereignty challenges					
Poor technical skills of content creators, no product management and design skills					
The lack of strategic thinking and vision in the industry					

Q1-11. To what extent do you agree with the following statements?

The following statements were collected through open questions in the first round of the Delphi survey. Thus, we would like to ask your views on it.

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
EU could create a central body that helps unifying access to resources and info that aids those creating legal frameworks and training plans					
More grants are needed for EU citizens specially designed for the development of XR/Metaverse industry.					
It would be foremost important to support innovation through more Horizon funding via a multidisciplinary approach for application areas in the metaverse (including XR, AI, 5G, cloud)					
Adoption in Europe seems slower versus North America and Asia					
Effective XR adoption requires focusing on niche markets unique to XR rather than applying XR to existing markets					

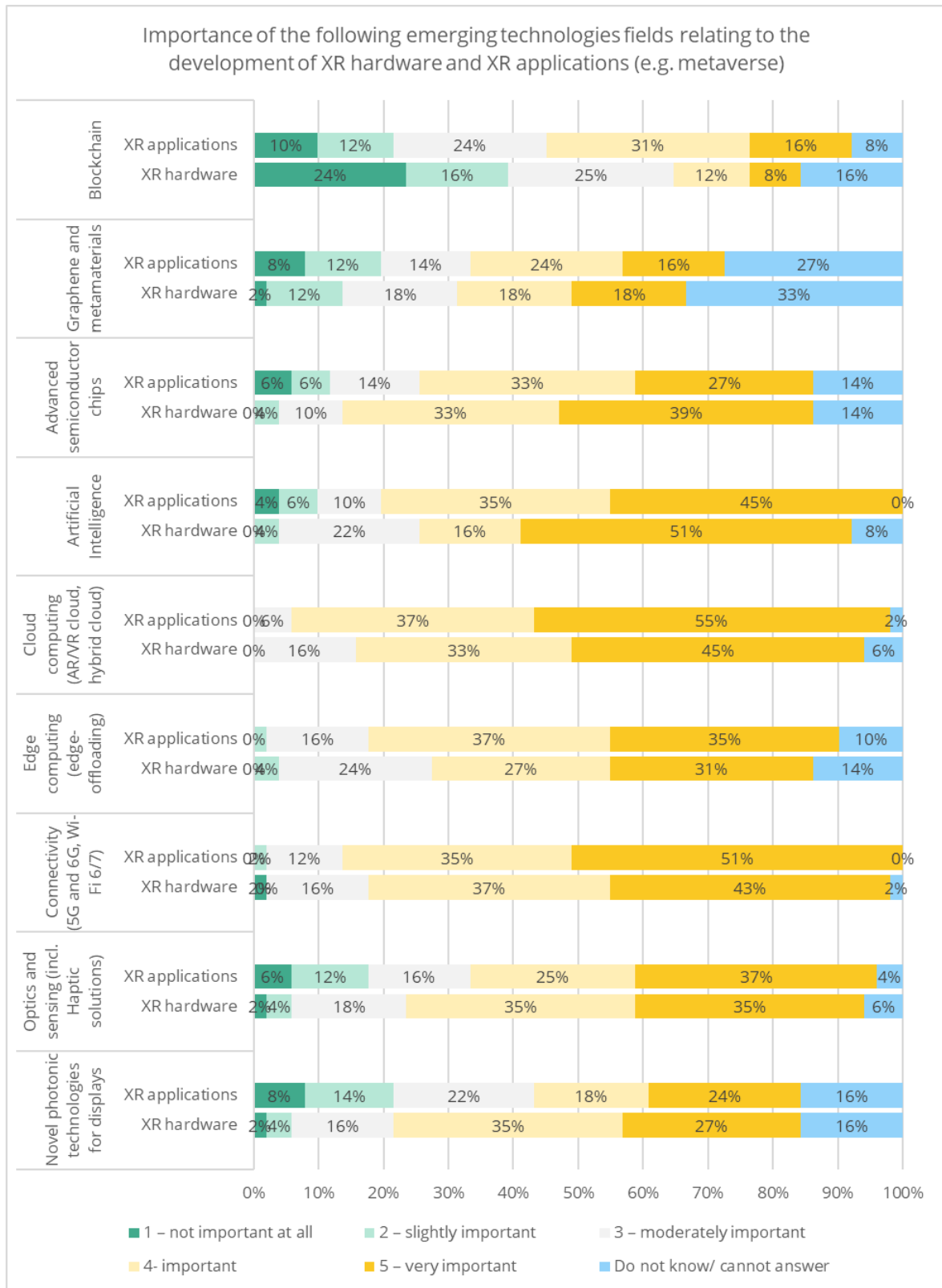
Q2-12. Do you have any other thoughts or comments on the role of XR technologies in the EU industry that you would like to share?

--

Part 2: The potential and impact of emerging technologies on XR

The figure below illustrates aggregated results from all sectors, from the first round of Delphi survey. The results suggest couple of findings. Emerging technologies are important or very important according to Delphi survey respondents. However, some fluctuations were noted:

- Blockchain appeared to be less important technology for development of XR hardware (40% who selected that technology is not important at all or slightly important), and XR applications, incl. metaverse (22%).
- While the vast majority of respondents answering the question about XR hardware indicated that the emerging technology is at least moderately important, some more fluctuations were noticed in respondents' answers about XR applications, incl. metaverse. In addition to blockchain, experts evaluate novel photonic technologies (22% think that it is not important at all or only slightly important), graphene and metamaterials (20%), and optics and sensing (18%) as less important in question about XR applications, incl. metaverse.



Note: N=51

Source: Delphi survey, round 1, 2023.

Q2-1. To what extent do you agree with these findings:

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
Blockchain is less important emerging technology for development of XR hardware and application of XR (incl. metaverse)					
All listed emerging technologies are at least moderately important to the development of XR hardware					
Novel photonic technologies are less important for development of application of XR (incl. Metaverse) than other emerging technology fields					
Graphene and metamaterials are less important for development of application of XR (incl. Metaverse) than other emerging technology fields					
Optics and sensing are less important for development of application of XR (incl. Metaverse) than other emerging technology fields					

Q2-2. Please elaborate on your answer. If you have any comments on findings, please note them here.

--

Q2-3. In your opinion, why importance of emerging technologies differs for XR hardware and XR application (incl. metaverse) development?

--

Q2-4. To what extent do you agree with the following statements?

The following statements were collected through open questions in the first round of the Delphi survey. Thus, we would like to ask your views on it.

	Strongly agree	Agree	Disagree	Strongly disagree	Do not know/ cannot answer
The use of suits, gloves, and scents to complement the experiences needs improvement and more accessible costs					
Hand tracking algorithms could break through current technology limitations and accelerate the development of metaverse and wider uptake of XR					
Embodiment is an important field that still needs improvement and that is essential to complement the immersive experience					
There remains a great deal of work to be done on energy management and storage for wearable devices					
Security (lack of secure authentication and access to highly sensitive data not on the user's device) is a barrier to wide-					

scale adoption in the industrial and enterprise/defence sectors					
Automatic 3D content generation through AI could break through current technology limitations and accelerate the development of metaverse and wider uptake of XR					

Q2-5. Do you have any other thoughts or comments on potential and impact of emerging technologies on XR?

Thank you

Your participation in this survey will provide valuable insights that will help shape the future of XR in the EU industry. Thank you for your time and expertise.

Annex 6: Case studies

Case study #1: Digital Catapult

Table 19. Overview of Digital Catapult

Geographic area	Europe
Country	United Kingdom
Website (if available)	https://www.digicatapult.org.uk/
Budget	£1.2 billion (overall Catapults funding - see body text)

Objectives and scope

Digital Catapult is the British government innovation agency for the digital and software industry. It is part of the UK Catapults network, an array of technology and innovation centres spanning multiple sectors to deliver innovation by connecting the government with industries and researchers.

The agency is funded as part of the UK's Digital Strategy, which aims to consolidate and maintain the UK's supremacy in Europe regarding tech innovation, as well as making sure digitalisation is widespread around the country, and young talents and tech enterprises continue to grow and be supported. The Digital Strategy covers most of the technological sectors, including new developments, such as artificial intelligence and quantum technologies.

Digital Catapult, within this ambitious plan, is to serve as an accelerator for new start-ups and established businesses alike, as well as to work with the public sector, academic institutions, associations, investors, and venture capitalists, in order to promote the growth of the technology environment. The focus within the agency is on three expertise areas: virtualisation, supply chains, and digital infrastructure. This case study will explore their activities of virtualisation, which includes three key active initiatives:

- The Advanced Media Production Facility, 'Studios UK', a fully equipped facility that facilitates full-scale productions and research and development efforts. Its primary aim is to encourage media production using new technologies, as well as cross-technology experimentation. The facility offers access to a range of cutting-edge technologies including XR, AI, 5G, cloud rendering, and edge computing. It is open to businesses, individuals, and researchers.²⁵⁵
- The MyWorld programme, based in the West of England, is a cooperation between the University of Bristol and 30+ media companies from the area. Its work is focused on forging a lasting network and relationships between XR companies and/or researchers, providing funding and technical support for businesses of all sizes. Its goal is to find and tackle the main challenges to the industry in the West of England, known to be an industry hotspot for audio-visual entertainment.²⁵⁶
- The Design Smarter Digital Twins project, a 5-years endeavour in collaboration with industrial partners, aims to build a digital twinning and cyber physical infrastructure centre, the first in the UK, called DT Hub. The goal of the project will be to 'support industry adoption of digital twins and complex cyber physical systems, with a focus on high fidelity and real-life industry challenges'.²⁵⁷

²⁵⁵ Digital Catapult, available at: <https://www.digicatapult.org.uk/apply/labs/advanced-media-production/>

²⁵⁶ Interview with Digital Catapult representative, 2023 April 3

²⁵⁷ Digital Catapult, available at: <https://www.digicatapult.org.uk/expertise/virtualisation/>

Additionally, there are several agency-wide initiatives that may also have relevance for the virtualisation ecosystem. These include the Digital Manufacturing Programme, which provides innovation support to manufacturing, construction, and automotive businesses; Critical Dialogues, an interactive installation seeking to provoke ideas about future uses of technology applications; and the 'Made Smarter' Technology innovator, a national accelerator programme for the manufacturing sector.

Digital Catapult was established in 2013 by the UK Government in cooperation with UKRI – Innovate UK (the UK's public body for innovation). In the virtualisation area, it can count on many completed projects and initiatives, among others:

- 5G VISTA, related to multimedia Broadcast and Multicast service (FeMBMS) technology for events organization, and 5G Festival, a live immersive hybrid concert that saw the performances of 21 artists, and harnessed the potential of 5G and immersive technologies for the music industry. These two projects were part of the government's £200 million '5G Testbeds and Trials Programme' of investment in 5G.²⁵⁸
- CreativeXR, a 3-year project that saw 20 small teams create a content distribution platform, to promote the grassroots use of immersive technology in the creative industry. The project assisted participants up to the prototype stage.²⁵⁹
- Augmentor, a recurring 12-week programme started in 2017-2018 that ran up to 2020 delivering business and technical mentorship for augmented reality applications.²⁶⁰
- 'Audience of the Future', funded by UKRI and run from 2017 to 2020.²⁶¹ It saw the cooperation of Digital Catapult as a facilitator, to convene the numerous actors involved, and as a research entity, a role that produced a landscape report on the UK immersive industry environment, and an Immersive Audience Journey report.²⁶² These were themes that the demonstrators involved found particularly salient to their needs.²⁶³

The UK Department for Digital, Culture, Media, and Sport has supported the Catapults programme, including Digital Catapult, with direct public funding of £1.2b for the period 2018-2023.²⁶⁴ While detailed information on funding is limited, some initiatives have disclosed their budget publicly online: the MyWorld initiative has been supported by UKRI with an investment of £30m, expected to boost the local economy by £223m.²⁶⁵ Audience of the Future has invested £39.3m in the development of new immersive technologies.²⁶⁶ Finally, the 5G Festival saw an investment of around £5m from the Catapult and its partners.²⁶⁷

While some virtualisation initiatives are still ongoing, they have already achieved many successes. The MyWorld initiative is already working with tech giants, such as Netflix, Microsoft, and Google.²⁶⁸ The 5G VISTA project saw the cooperation of the Catapult with nine different industry partners, some as important as Virgin Media O2. The DT Hub already counts 3,500 individual members, representing more than 1,600 Organisations, from nearly

²⁵⁸ Digital Catapult, 'Annual Engagement & Impact Report 2021-2022', pp.43.

²⁵⁹ Interview with Digital Catapult representative, 2023 April 3

²⁶⁰ Digital Catapult, available at: <https://www.digicatapult.org.uk/expertise/programmes/programme/augmentor/>

²⁶¹ Audience of the Future, available at: <https://audienceofthefuture.live/about/>

²⁶² Full reports available at: <https://audienceofthefuture.live/in-depth/#reports>

²⁶³ Interview with Digital Catapult representative, 2023 April 3

²⁶⁴ Department for Digital, Culture, Media and Sport, available at: <https://www.gov.uk/government/publications/uks-digital-strategy/uk-digital-strategy#annex>

²⁶⁵ Digital Catapult, available at: <https://www.digicatapult.org.uk/about/press-releases/post/myworld-pioneering-startups/>

²⁶⁶ UKRI, available at: <https://www.ukri.org/what-we-offer/our-main-funds/ukri-challenge-fund/artificial-intelligence-and-data-economy/audience-of-the-future-challenge/>

²⁶⁷ Digital Catapult, available at: <https://www.digicatapult.org.uk/expertise/case-studies/study/5g-festival/>

²⁶⁸ Digital Catapult, available at:

80 countries.²⁶⁹ The Augmentor programme was also a success, with participants from 10 countries across the world harnessing investment for over £3.1m.²⁷⁰

Assessing the impact at a global level for the XR industry and EU strategic autonomy

As discussed in the section above, Digital Catapult has successfully implemented a large number of initiatives for the immersive environment over the years. The quality of their industry engagement is also high, as evidenced by collaborations with established international brands, such as Nvidia, Amazon, and Unity animation. Most initiatives can be considered successful in many ways, including the engagement generated and the funding raised.

Digital Catapult focuses on reducing business barriers in XR adoptions for businesses of all sizes.²⁷¹ This means making technology that is often expensive, such as visors or simulators, available to smaller businesses, removing the risk connected to investment in hardware.²⁷² Conversely, larger businesses face different challenges and barriers, with the most prominent being change management within the enterprise once ambitious plans for adoption of XR are brought forward. In these cases, Digital Catapult helps the companies find long-lasting value for the business in using XR, by incorporating the technology in long-term business plans. This often means 'starting small', by experimenting with XR in a single straightforward use case, and then extending the technology one phase at a time.²⁷³

In European ecosystems, these business-related challenges are also present and would benefit from agencies, such as Digital Catapult. For example, the issue of hardware cost is particularly felt by the agri-food and health ecosystems, while the inadequacy of business models is prominent in the tourism and agri-food sectors.²⁷⁴ European SMEs across sectors, moreover, would benefit in mentorship, such as what Digital Catapult offers, as they often struggle to integrate immersive technologies in their operations and workflow.²⁷⁵

In many cases, Digital Catapult helps businesses in solving struggles where there is still little research available. Many barriers still need to be broken by businesses on the road to XR adoption, such as ethical questions, and issues of privacy and security.²⁷⁶ This is part of Catapult's work and could deliver interesting results in the long-term. For instance, a particular sector that Digital Catapult is starting to work with is energy-intensive industries. While the transition to XR technologies in this area is a slow process, the Digital Twins initiative is slowly working on identifying best practices in technology change for heavy industries. Although the project is just starting out, if successful, it could represent a replicable initiative for European enterprises, which, similarly to the UK, have been relatively slow in incorporating immersive technologies into their workspaces.²⁷⁷

Case study #2: Metaverse Seoul

Table 20. Overview of Metaverse Seoul

Geographic area	Asia
Country	South Korea

²⁶⁹ Digital Catapult Progress Report 2022, available at: <https://www.digicatapult.org.uk/wp-content/uploads/2022/11/Digital-Catapult-AR22-FINAL-2.pdf>

²⁷⁰ Digital Catapult, available at: <https://www.digicatapult.org.uk/expertise/programmes/programme/augmentor/>

²⁷¹ Ibid.

²⁷² Ibid.

²⁷³ Ibid.

²⁷⁴ See chapter 2.4 of this report..

²⁷⁵ Ibid.

²⁷⁶ Interview with Digital Catapult representative, 2023 April 3

²⁷⁷ See chapter 2.2 of this report.

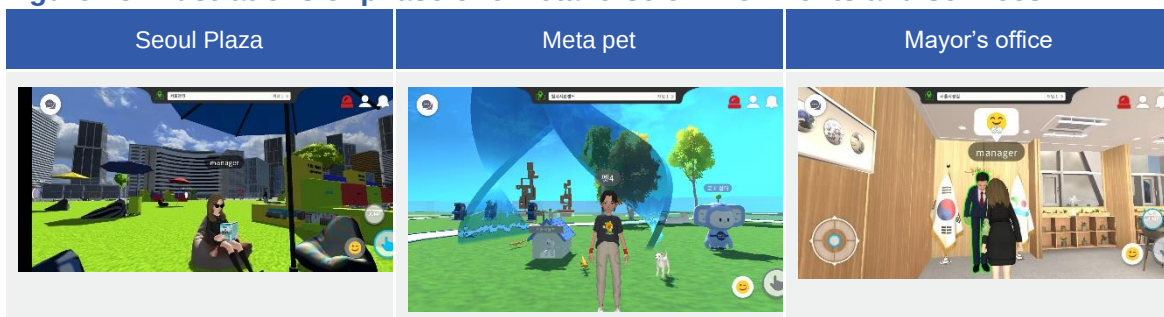
Website (if available)	http://metaverseseoul.kr/user/
Budget	40.5 billion won (approx. €27,879,500) - estimate

Objectives and scope

Metaverse Seoul is a ground-breaking initiative, being the first public metaverse worldwide. It is a fully public initiative by the Seoul Metropolitan Government (SMG). Metaverse Seoul is part of the city's broader digital policy efforts, which aim to convert Seoul into 'a future smart standard city leading digital transformation'.²⁷⁸ Metaverse Seoul is designed to become a space for citizens to connect with businesses and institutions, and even take virtual tours of tourist hotspots. The main services offered include the following:²⁷⁹

- Creation of a participatory space that citizens can enjoy together, featuring virtual locations, such as the Seoul Mayor's office and Seoul Plaza, which includes an open e-book library.
- Industry support through public relations and investment consultations for the industrial ecosystem. The Metaverse Fintech Lab enables participating companies to hold fairs and establish promotional booths for Metaverse users.
- Provision of the 'Avatar Counselling Room', where teenagers can get virtual psychological counselling.
- Tax inquiry services and tax advice through local tax education and AI chatbots.
- Issuance of documents and certificates, such as resident registration copies, in the Metaverse.
- Civil complaint counselling for overall administrative matters in Seoul.
- Virtual replicas of Seoul's top 10 most loved attractions allowing foreigners and locals to visit virtually.
- Live chat function with built-in English translation.
- Spaces where citizens can raise virtual pets, engage in mini-games, participate in contests, and solve quizzes about city policies.

Figure 28. Illustrations of phase one Metaverse environments and services



Source: Seoul Metropolitan Government.

Metaverse Seoul is already operational and accessible to individuals who follow the instructions provided on the website, which includes identity verification through South

²⁷⁸ Seoul Metropolitan Government, available at: <https://news.seoul.go.kr/gov/archives/2092>

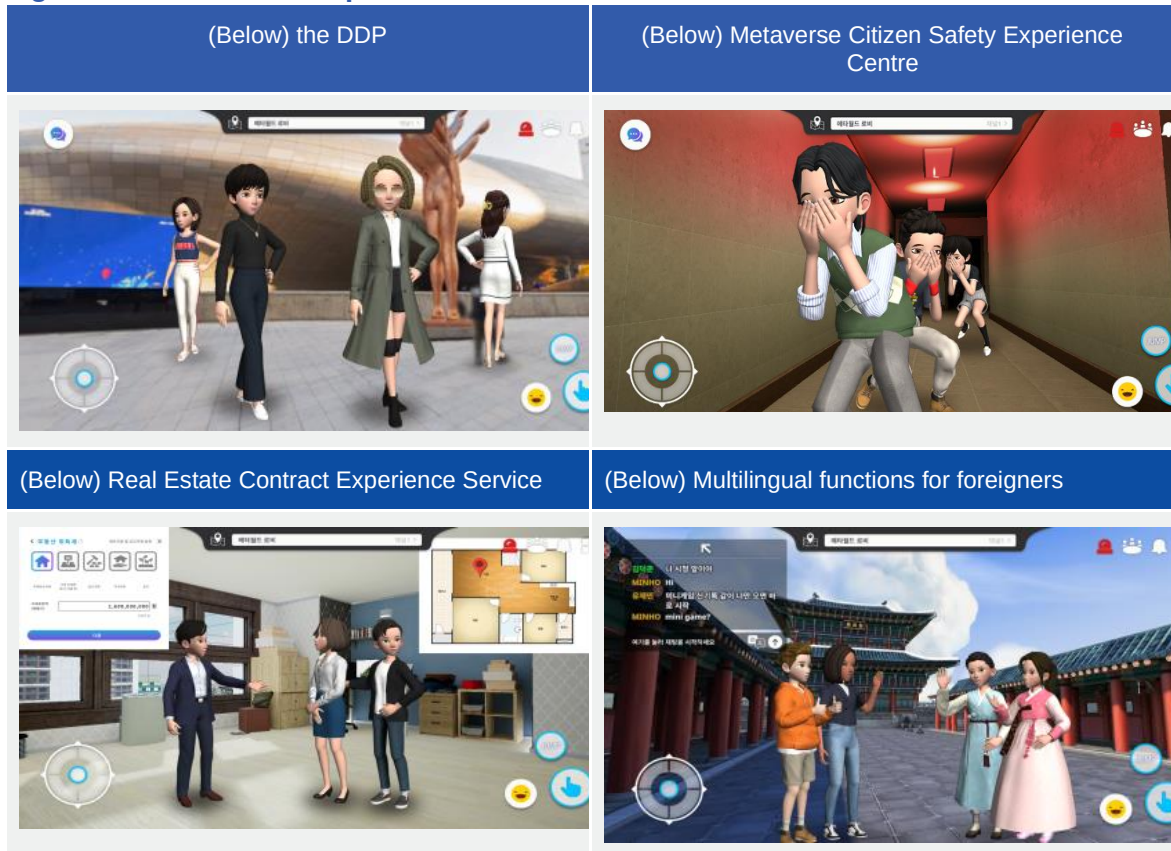
²⁷⁹ Seoul Metropolitan Government, available at: <https://news.seoul.go.kr/gov/archives/544743> ;

Written interview with Seoul Metropolitan Government employee, 03/05/2023

Korean service providers. Overall, the initiative is designed as a five-year plan, divided into three stages: the ‘introduction’ phase (2022), focused on the designing and developing the metaverse and its spaces and services; the ‘expansion’ phase (2023-2024), currently in progress, which involves the introduction of new functions;²⁸⁰ and the ‘settlement’ phase (2025- 2026).²⁸¹

- Exhibition space for artists and companies will be created through the Metaverse Dongdaemun Design Plaza (DDP).
- Metaverse Citizen Safety Experience Centre, where citizens will be able to experience emergency scenarios (earthquakes, fires, typhoons...), and learn evacuation and safety practices.
- The Real Estate Contract Experience Service, to help first-time tenants rent safely.
- Expansion of the multilingual version and functions for visiting foreigners.

Figure 29. Illustration of phase two Seoul Metaverse environments and services



Source: Seoul Metropolitan Government.

The ‘settlement’ phase will be built around a planned citizens’ demands survey, which will determine what tangible services are most needed by citizens in the Metaverse. This phase also foresees a focus on the public’s engagement and immersion in the virtual world.²⁸²

The funding provided by the SMG for the ‘introduction’ phase amounted to 2,075 million won (approx. €1.431.283,45) in 2022. For the year 2023, the initiative has been allocated an estimate of 2,304 million won (approx. €1.586.032,13) for ‘construction costs’, related both to the operation of existing services and the addition of new ones (‘expansion’

²⁸⁰ Written interview with Seoul Metropolitan Government employee, 03/05/2023

²⁸¹ Smart Cities Connect, available at: <https://smartcitiesconnect.org/seoul-will-invest-in-metaverse-communications-platform-for-city-services/>

²⁸² Interview with Seoul Metropolitan Government employee, 03/05/2023

phase).²⁸³ The overall estimated funding that was announced in 2021 to be allocated to all three phases is 40.5 billion won (approx. 27.879.471,00 €). However, the exact budget is, and will be, allocated on a yearly basis, making it challenging to provide an exact breakdown of funding for each phase or determine the overall funding amount at this time.²⁸⁴

Assessing the impact at a global level for the XR industry and EU strategic autonomy

At the time of writing (April 2023), the Metaverse of Seoul has been operational for a few months, not long enough to assess its impact on society. As of May 2, 2023, the number of cumulative visitors to Metaverse Seoul was 45,629, and the number of app installations was 16,907.²⁸⁵ For context, the population of Seoul is estimated at more than nine million people.²⁸⁶

However, the initiative has attracted lots of local and international press, making this perhaps the most popular and widely discussed initiative among the case studies in the scope of this study. Metaverse Seoul was selected as the '2022 Best Inventions 200' by Time Magazine in November 2022.²⁸⁷ It is also in constant growth, and it is designed to become a permanent service beyond the three initial phases. In fact, the reason why the government decided to build its own metaverse platform is to provide a permanent, reliable service to citizens, in expectation of a generalized growth of the metaverse as a publicly widespread technology.²⁸⁸

The great public attention generated by the initiative and the publicity that followed present an opportunity to address the challenge of limited user adoption of XR technologies in Europe. Furthermore, tying metaverse technologies to public services that are highly useful for the citizens, and putting the initiative at the forefront of city policy, could ultimately contribute to changing public attitudes towards the metaverse, encouraging greater popular acceptance and awareness of virtual reality technologies.

The Metaverse also represents a conspicuous opportunity for XR businesses and traditional ones alike to use the newly created virtual environment, to widen their audience, advertising their services in virtual showrooms, and connecting with other enterprises in their field. They can also benefit from increased technological demand for XR, which will be generated by the initiative itself (which will need technical support and development), but also by a possible societal change in favour of more widespread XR adoption.

A public metaverse in Europe, on a local, or even pan-European scale, could bring similar benefits:

- Enterprises belonging to all European ecosystems could leverage the metaverse as an advertising platform and a networking hub, allowing different actors to connect and collaborate without the need for physical presence.
- The cultural and creative industries would have an unprecedented opportunity to sell and showcase their XR-based work, such as virtual motion picture productions, but also to craft events and immersive experiences for the public, similar to the Festival of Lanterns, planned by Metaverse Seoul.²⁸⁹

²⁸³ Ibid.

²⁸⁴ Ibid.

²⁸⁵ Ibid.

²⁸⁶ Seoul Metropolitan Government, available at: <https://english.seoul.go.kr/seoul-views/meaning-of-seoul/4-population/>

²⁸⁷ Written interview with Seoul Metropolitan Government employee, 03/05/2023

²⁸⁸ Ibid.

²⁸⁹ Creatori di Futuro, available at: <https://creatoridifuturo.it/nuove-tecnologie-e-web-2-0/seoul-metaverse-la-prima-grande-smart-city-del-futuro/>

- The digital ecosystem would increase its relevance in developing the metaverse itself, but also by servicing other businesses that want to get access to it, in a development similar to the current project of the Luxembourg Metaverse.²⁹⁰ The electronics ecosystem would be able to focus on developing and refining XR and VR hardware, benefitting from increased revenue from their sales.
- The retail and tourism ecosystems would be able to create ad-hoc products to use in the metaverse, such as avatar outfits and virtual tours. These products are already being experimented with in Europe,²⁹¹ and could be more sustainable and/or energy efficient, as well as more cost-effective, than their traditional counterparts.
- Lastly, providing public services in the metaverse could make citizens' relationships with public institutions easier and more streamlined, improving the efficiency of service (e.g., reducing wait times and providing integrated services, with different public services all in one place), and cutting costs. It would also improve sustainability as fewer citizens would commute.

Case study #3: RLab

Table 21. Overview of RLab

Geographic area	North America
Country	USA
Website (if available)	https://edc.nyc/program/virtual-reality-and-augmented-reality-lab-vrar-lab
Budget	\$5.6 million USD (initial funding) - approx. € 5,184,144.00

Objectives and scope

RLab is a public initiative funded by the New York Mayor's Office of Media and Entertainment and NYCEDC, a non-profit organization that aims to strengthen local communities in NY, by creating jobs and opportunities for citizens and businesses. It is part of an overarching policy, the 'New York Works' plan, launched in 2017 to generate 30,000 well-paying technology jobs in the city.²⁹² RLab will be initially administered through the NYC Media Lab consortium, created by the city to promote innovation and its adoption across a variety of social actors.

RLab will take the form of a physical space, a VR laboratory available to startups, businesses, community organizations, students, and universities. Its listed main objectives are the following:

- *Support New Ventures*, by providing funding, workspace, equipment, mentorship, networking opportunities, and resources to start-ups.
- *Expand and Increase Access to the Talent Pipeline* by cooperating with universities to create education programs, scholarships, and learning opportunities for students.
- *Foster Research* by creating the preeminent VR/AR research centre in the country, thanks to strong ties to main university institutions.
- *Build VR/AR Community* through programming and events, including community outreach programs.

²⁹⁰ Research Luxembourg, available at: <https://www.researchluxembourg.org/en/a-future-digital-twin-for-luxembourg-in-the-metaverse/>

²⁹¹ See chapter 2.2 of this report.

²⁹² Tandon School of Engineering, available at: <https://engineering.nyu.edu/news/unveiling-rlab-first-city-funded-vrar-center-country-opens-doors-brooklyn-navy-yard>

- *Spur Corporate VR/AR Innovation* by extending cooperation with companies through projects and corporate innovation programmes.

RLab's facility was completed in 2019. Examples of early projects completed are:²⁹³

- XR start-up bootcamp to develop startup concepts on a variety of topics ranging from 3D modelling to VR and robotics, involving NYU, Columbia, CUNY, The New School, and Pratt Institute.
- RLab training programs to help start-ups and entrepreneurs learn about XR technologies and their applications, in partnership with the Lehman College VR Training Academy, which is partnering with Eon Reality and The Knowledge House.
- A series of trainings and workshops in applications of virtual and augmented reality for journalism, organized by the Craig Newmark Graduate School of Journalism at CUNY.
- A fellowship program to create work-study and training opportunities created by the Macaulay Honors College at CUNY.
- The "Storyteller in Residence" award, with the goal of increasing social engagement with AR/VR, launched by Eyebeam, a Brooklyn-based platform for artists to engage society's relationship with technology.

The initial funding from the City's Mayor Office of Media and Entertainment amounted to \$5.6 million.

Assessing the impact at a global level for the XR industry and EU strategic autonomy

While the initiative generated a lot of interest initially in 2018, especially from the universities involved, there is limited recent information available regarding Rlab. Currently, there is a lack of recent news regarding ongoing projects, or the continued operation of the laboratory.

However, a laboratory that provides community space and supports enterprises with funding and mentorship, could be an asset for Europe as well. In particular, the community engagement component would help boost user awareness of XR technologies and increase their confidence in them, through ad-hoc programs that show the benefits of XR against more traditional technologies. These initiatives could also have useful, if unrelated, social benefits, such as youth engagement and social integration. Meanwhile, businesses would benefit from improved access to funding at all levels, and an increasingly coordinated and organized European XR environment.

European ecosystems where financial and business-related barriers are particularly strong would benefit greatly from this initiative. For example, the digital, cultural and creative industries, and proximity, social economy, and civil security ecosystems would be able to access funding, which is currently scarce.²⁹⁴ Effective mentorship provided on-site by the labs could also help with establishing more effective business models, which are rather ineffective in some European ecosystems, such as agri-food and tourism.²⁹⁵ If the initiative were to be implemented across EU Member States, with multiple interconnected laboratories, the industry could benefit from European integration and growth, enabling Europe to better compete in the global XR market. This would be particularly relevant for

²⁹³ Ibid.

²⁹⁴ See chapter 2.4 of this report.

²⁹⁵ Ibid.

the aerospace and defence, digital, electronics, and cultural and creative industry ecosystems.²⁹⁶

SMEs and start-ups in all fields would be able to experiment with, and perhaps adopt, XR technologies, especially where there is untapped potential. For example, the agri-food sector could experiment with, and start using on a bigger scale, XR technologies for training, education, or remote collaboration.²⁹⁷ Similarly, the energy renewables sector could benefit from widespread use of XR in all Member States, while these applications are now concentrated in Northern Europe.²⁹⁸

Strong community engagement through designated collaborative projects could foster expertise development in education and training, with programs that incorporate XR experimentation and use.²⁹⁹ This would also raise public awareness and confidence in XR technologies, addressing barriers to adoption in European ecosystems, namely agri-food, energy-intensive industries, energy renewables, retail, textile, and tourism.³⁰⁰

Case study #4: Metaverse Customer Happiness Service Centre (Metahealth)

Table 22. Overview of Metaverse Customer Happiness Centre

Geographic area	Asia
Country	UAE
Website (if available)	https://www.ehs.gov.ae/en/metaverse
Budget	Unknown fraction of AED 53.7m (approx. €13.6m)

Objectives and scope

The ‘Metaverse customer happiness service centre’, or Metahealth, is an initiative led by the Ministry of Health and Prevention of the UAE. It has been presented at the Arab Health exhibition in 2022³⁰¹ as part of a broader intention to develop virtual world-related public services in line with the UAE's Fourth Industrial Revolution (4IR) policy strategy.³⁰² The 4IR strategy encompasses various technologies, including ‘artificial intelligence, blockchain, virtual and augmented reality’.³⁰³

Metahealth is envisioned as a customer service centre situated in the virtual world, which citizens will be able to access through the Ministry of Health website, using their real identities, including facial features. Its aim is to assist the general public and individuals who may face physical limitations. Users will be able to ‘request information, submit documents, pay fees and more’.³⁰⁴ It could also offer an alternative to in-person hospital or GP visits.³⁰⁵ Another goal of the initiative, as it was presented at the Arab Health exhibition, was to showcase the digital and technological advancement of the UAE healthcare sector to the

²⁹⁶ Ibid.

²⁹⁷ See section 2.2 of this report.

²⁹⁸ Ibid.

²⁹⁹ Ibid.

³⁰⁰ See section 2.4 of this report.

³⁰¹ Arab Health website, available at: <https://www.arabhealthonline.com/en/Home.html>

³⁰² The UAE's Fourth Industrial Revolution (4IR) Strategy, available at: <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/government-services-and-digital-transformation/the-uae-strategy-for-the-fourth-industrial-revolution>

³⁰³ UAE Ministry of Health, available at: <https://mohap.gov.ae/en/media-center/news/25/1/2022/ministry-of-health-launches-worlds-first-metaverse-customer-happiness-service-center>

³⁰⁴ Ibid.

³⁰⁵ TMRW Foundation, available at: <https://www.tmrw.com/mohap-customer-service-center-launch/>

international scene. In fact, other services planned for the Metaverse by the Ministry include a Metaverse Mental Health Clinic, and a Metaverse Family Health Promotion Clinic.³⁰⁶

The initiative was presented in January 2022, and was due to be implemented by mid-2022, but there seems to be no evidence yet of its launch. The Ministry considers this initiative as a pilot project; citizens will be able to benefit further from the use of virtual reality technology, which will be gradually extended to become a crucial part of the UAE healthcare sector over the next 50 years.³⁰⁷

The platform was developed by the TMRW Foundation, a web3 company based in Luxembourg, for the UAE Ministry of Health and Prevention.

Metahealth is part of an Emirates Health Service (EHS) funding cohort that funded three projects: 'Metahealth', 'Community Mental Health', and the 'Integrated Revenue Cycle Management System'. The budget allocated by the EHS to all three initiatives is AED 53.7 million (approximately €13.6m as of 06/06/2023); however, the exact amount dedicated to Metahealth has not been specified.³⁰⁸

Assessing the impact at a global level for the XR industry and EU strategic autonomy

The Metahealth initiative is on the verge of becoming operational and its impact will be determined once it is fully implemented. At present, it has garnered significant attention from the press, especially within the UAE, and a few foreign specialized news outlets, such as xrtoday.com, cryptonomy.ch, or NFTgators.com.

The Metahealth initiative provides noteworthy examples of how to address barriers within the XR industry:

- The initiative does not seem to require users to own a virtual reality visor, as it seems to be planned to be accessible through a simple browser, even though a visor would make the experience more immersive. This could broaden its public adoption, as it cuts costs for the consumer, but also because it would help users get more familiar with the technology.
- It could also boost public confidence in XR, if the public finds that the platform significantly improves their quality of life and is easy to use.
- The initiative employs RealityOS, a trademarked software platform developed by TMRW, known for providing an abstraction of reality and computing resources through virtualisation technologies. This comprehensive software solution for XR applications could break existing barriers to limited software availability for similar initiatives.

In Europe, an initiative of this kind could benefit the health ecosystem through increased efficiency of medical practices, reducing physical lines at healthcare centres and could provide greater accessibility for patients who have limited mobility. This would also increase the sustainability of the European health ecosystem, as citizens who would normally travel to the healthcare centre for small errands (such as asking for a medical certificate or prescription), would not need to leave the house, without compromising on human interaction.

³⁰⁶ Emirates Health Service, available at: <https://www.ehs.gov.ae/en/metaverse>

³⁰⁷ UAE Ministry of Health & Prevention, available at: <https://mohap.gov.ae/en/media-center/news/25/1/2022/ministry-of-health-launches-worlds-first-metaverse-customer-happiness-service-center>

³⁰⁸ Day of Dubai, available at: <https://www.dayofdubai.com/news/emirates-health-services-presents-three-major-transformational-projects-board-meeting>

Case study #5: Queensland XR Hub

Table 23. Overview of Queensland XR Hub

Geographic area	Australia and Oceania
Country	Australia
Website (if available)	https://qldxrhub.com/
Budget	Unknown

Objectives and scope

Queensland XR Hub is a public initiative of the State Government of Queensland. It consists of a hub for advancing knowledge and expertise in the field of XR, aiming to develop the local industry through local capabilities to promote sustainable XR ecosystem growth in Queensland. The initiative is co-funded by Advance Queensland and Screen Queensland.

Screen Queensland is a publicly available film studio facility and state government-owned screen agency that invests in 'locally produced films, series, and games, and secures international and interstate production and post-production into Queensland.'³⁰⁹ The Hub was created within Advance Queensland, an initiative for innovation promoted by the Queensland government.³¹⁰ Among its other activities, it offers a physical space to advance its aims, called 'the Precinct', which is where XR Hub is headquartered.³¹¹ All initiatives tied to Advance Queensland are part of a broader state strategy for innovation called 'A Place to Innovate', encompassing the entire innovation ecosystem.³¹²

The resources and benefits offered by the XR hub, such as personalized advice, consultations, access to archives, networking opportunities and tenders, are available to members. Membership is free to students and community groups, while professionals, businesses, start-ups, and corporations are subject to a variable fee. The XR Hub has currently 44 members and has launched 35 initiatives in total.³¹³

The XR Hub focuses on five key goals:³¹⁴

- Building on Queensland's emerging Immersive Technologies capability and community, to create jobs in the local XR industry.
- Developing local talent and supporting local Immersive Technology startups.
- Assisting local industry, corporate, and government organisations to better understand and engage with Immersive Technologies through education and events, in cooperation with industry partners (e.g. 'Brennan's XR Friends', a meet-up organized with two companies working in XR, Real Serious Games and Equal Reality), or universities (e.g., The 'University of Qld XR cybersecurity project' in cooperation with the University of Queensland). These often have a strong educational component, and are aimed at spreading knowledge about the possibilities and characteristics of XR technologies, in key corporate and governmental sectors.³¹⁵

³⁰⁹ Screen Queensland, available at: https://www.facebook.com/screenqueensland/about_details

³¹⁰ Advance Queensland, available at: <https://advance.qld.gov.au/about>

³¹¹ More information on the Precinct is available at: <https://advance.qld.gov.au/precinct>

³¹² More information on 'A Place to Innovate' available at: <https://advance.qld.gov.au/queensland-innovation-precincts-and-places-strategy>

³¹³ Interview with XR Hub representative, 03/05/2023

³¹⁴ Advance Queensland, available at: <https://advance.qld.gov.au/xr-hub>

³¹⁵ Interview with Queensland XR Hub representative, 03/05/2023

- Promoting Queensland's XR capabilities nationally and internationally.
- Supporting initiatives to increase investment in emerging Immersive Technology businesses.

Since 2021, the XR Hub has been part of 17 events in various capacities organising, facilitating, and collaborating with industries. These events have covered XR technologies in fields such as emergency services, the water industry, advanced manufacturing, the virtual worlds, sports, the aerospace industry, cybersecurity and privacy.

Additionally, there have been events focused on industry and business development, such as accounting, intellectual property law, accounting, strategic considerations, for SMEs and social media monitoring.³¹⁶

Another publicly available outcome of the XR Hub is a Queensland start-up, HINDSITE industries, which secured 80 000 AUD in funding from aerospace colossus Boeing, after winning a pitch competition organized by the Hub.³¹⁷ XR Hub had previously organized presentations and networking events on the theme of aerospace uses of XR, where Boeing was one of the participants.³¹⁸ The Hub turns success stories into case studies, which are then published on their website;³¹⁹ one such case study is the Greater Whitsunday Virtual Reality Tour, which is the outcome of a collaboration between the XR Hub and the Greater Whitsunday Alliance, the independent regional economic development body for the Greater Whitsunday region of Queensland.³²⁰ In addition, the Hub also assists companies to draft tenders to invest in XR technology. This support is valuable as many industries may lack the specific knowledge required for this process. An example that can be found on the website is a tender from Energy Queensland published in 2022.³²¹

The Queensland XR Hub was born in 2020.³²² Due to the pandemic, the first year has not registered much activity. However, in 2022-2023, thanks to the success of the Boeing pitch event and the approaching of the 2032 Brisbane Olympics Games, the Hub has registered a rather exponential growth in membership, going from 12 members in April 2022, to 44 at the time of writing (May 2023).³²³

As of 2023, the Hub is entirely funded by public sources. Initially, the project received a lump sum and was expected to continue through September 2023.³²⁴ However, due to the Hub's success in creating jobs and opportunities in the industry, negotiations are underway to secure funding for additional years of operation.³²⁵ According to Karen Sanders, the CEO, the Hub would need to receive at least two more years of public funding before it can establish a successful business model. This is mostly due to the residual presence of many barriers in the local industry, such as prejudices regarding XR applications and potential uses.³²⁶ Nevertheless, it is the Hub's goal to be able to financially sustain itself and continue operations after government funding.³²⁷

³¹⁶ Full list available at: <https://qldxrhub.com/events>

³¹⁷ - Queensland XR Hub, available at: <https://qldxrhub.com/news/boeing-funds-qld-augmented-reality-tech-start-up>

Interview with Queensland XR Hub representative, 03/05/2023.

³¹⁸ More detail on the events available at: <https://qldxrhub.com/events/advmanvip> and <https://qldxrhub.com/events/advman>

³¹⁹ Interview with Queensland XR Hub representative, 03/05/2023

³²⁰ Queensland XR Hub, available at: <https://qldxrhub.com/news/the-greater-whitsunday-virtual-reality-tour-case-study>

³²¹ Queensland XR Hub, available at: <https://qldxrhub.com/tenders>

³²² Interview with Queensland XR Hub representative, 03/05/2023

³²³ Ibid.

³²⁴ Ibid.

³²⁵ Ibid.

³²⁶ Ibid.

³²⁷ Ibid.

Assessing the impact at a global level for the XR industry and EU strategic autonomy

As mentioned before, and given the relatively young age of the initiative, XR Hub seems to be headed for at least modest success. Some local press has been dedicated to the initiative, but was limited to media outlets in the tech/XR sector,³²⁸ and no international media picked up its creation. The Boeing success has especially attracted the attention of the local press. However, despite little news representation, XR Hub has already established ties with a good number of industry collaborators (35-36), and more collaborations are in the process of being created.³²⁹ Moreover, the Hub has raised \$3 million AUD in investment for XR applications so far, which is six times the amount that was expected at the time of its creation.³³⁰

This initiative provides some inspiration for the European XR industry; a member based XR Hub in Europe would help consolidate XR applications across ecosystems. The combination of funding and mentorship, along with the development of strong business plans, can attract significant investments to European XR industries, as seen with the Boeing partnership in Queensland. This, in turn, would also help boost European competitiveness in the global XR market, which is a point of weakness at present, especially for those ecosystems that are adopting XR technology more strongly.³³¹ Moreover, business-related guidance is still strongly needed in some sectors, such as the agri-food and tourism ecosystems, which struggle with creating effective business models for XR applications and with monetizing their XR content.³³² Services offered by the XR Hub, such as personalized legal advice on intellectual property law and help with designing effective corporate governance, have been found to be very helpful by Queensland start-ups, which are often led by experts in the tech sector that are still new to the business mechanisms of entrepreneurship.³³³

In numerous ecosystems where business barriers to XR are particularly high (e.g., textile, tourism, agri-food, health, construction, aerospace and defence, energy renewables, electronics, digital, cultural and creative media),³³⁴ start-up development, funding, and assistance, could increase XR uptake and consequently improve key areas of productivity,³³⁵ such as efficiency and effectiveness (e.g., Through development of XR training start-ups³³⁶), higher precision (e.g., through developing AR assistance software for construction³³⁷), or increased productive outputs (e.g., by creating remote warehouse management software for agri-food³³⁸). Throughout these ecosystems, the events and training opportunities created by the Hub would not only be aimed at creating expertise, but also at increasing technological standardization, improving the quality of existent software and its relevance for the targeted industries. For example, networking between different Hub members could help create XR standardization for use in the European health sector, which is currently fragmented by nature.³³⁹ The dialogue and software development could also trickle down to the technology ecosystems, stimulating them to enhance the quality of their hardware according to sectorial demands and the requirements of new software. This would be especially helpful in the European aerospace and defence ecosystem, which is struggling with software needs to meet its delicate demands.³⁴⁰

³²⁸ e.g., IT Brief Australia, available at: <https://itbrief.com.au/story/hindsite-wins-aerospace-xelerated-pitch-challenge-with-solution-to-support-boeing>

³²⁹ Interview with Queensland XR Hub representative, 03/05/2023

³³⁰ Interview with Queensland XR Hub representative, 03/05/2023

³³¹ See chapter 2.4 of this report.

³³² Ibid.

³³³ Interview with Queensland XR Hub representatives, 03/05/2023

³³⁴ See chapter 2.4 of this report.

³³⁵ Ibid.

³³⁶ See section 2.2 of this report.

³³⁷ Ibid.

³³⁸ Ibid.

³³⁹ See section 2.4 of his report.

³⁴⁰ Ibid.

Case study #6: 19 Units of Digital Transformation

Table 24. Overview of 19 Units of Digital Transformation

Geographic area	South America
Country	Argentina
Website (if available)	https://www.argentina.gob.ar/noticias/el-gobierno-aprobo-la-creacion-de-19-unidades-de-transformacion-digital-para-aumentar-la
Budget	88.045.431 ARS (approx. €352,000.00)

Objectives and scope

The initiative is part of the ‘Argentina Productive Development 4.0’ policy established by the Secretariat of Small and Medium Enterprises and Entrepreneurs (SEPYME). The policy program plans to deliver funding, infrastructure, and expertise to increase the digitalization of productive enterprises towards the industry 4.0 paradigm.

This initiative in particular mandates the creation of 19 units of digital transformation. These units will be created within existing institutions, which have each developed specific projects to engage with SMEs, and promote their adoption of Industry 4.0 technologies. The 19 institutions include universities, chambers of commerce, associations, and foundations located throughout the country. For the implementation of this initiative, the Argentinian government has been supported by the United Nations Development Program (UNDP).

While the single participating institutions involved differ in the activities and areas of expertise provided, they will all have to organize at least three workshops per year, engaging with at least 30 SMEs for each. They will also have to organize three seminars annually on Industry 4.0 technologies, such as AR/VR, IoT, AI, cybersecurity, or 3D printing. Collaboration among the institutions in each region is also expected to produce a specified number of ‘comprehensive plans of digital transformation’ (from 10 to 25 depending on the region).³⁴¹ The initiative also plans to create an online virtual advisory channel to serve as a repository for digital solutions and tools for enterprises.³⁴²

The funding for the initiative was announced in January 2022. Some of the institutions involved have already organised workshops and seminars, such as the ‘Information Management’ seminar at the Universidad Nacional de Mar del Plata,³⁴³ and the ‘Virtual and Augmented reality’ seminar at the Las Parejas Industrial Centre.³⁴⁴ However, due to the lack of a comprehensive website, it is challenging to track the overall progress of the initiative at this time.

The overall funding provided to the 19 Units of Digital Transformation by the Ministry of Economy amounts to \$88.045.431 ARS (approx. €347.707,43).

³⁴¹ Ministry of Economy, available at: <https://www.argentina.gob.ar/noticias/el-gobierno-aprobo-la-creacion-de-19-unidades-de-transformacion-digital-para-aumentar-la>

³⁴² Ibid.

³⁴³ Universidad Nacional Mar del Plata, available at: <https://www.mdp.edu.ar/utd/gestion-de-la-informacion/>

³⁴⁴ Las Parejas Industrial Centre, available at: <http://centroindustrial.org/category/utd/>

Assessing the impact at a global level for the XR industry and EU strategic autonomy

The initiative so far has generated several seminars, events, and workshops in at least six of the entities concerned.³⁴⁵ According to the entities' websites,³⁴⁶ participation in these events has been high, and the organizers possess significant expertise. This is valid for both XR-related events and unrelated ones, although XR represents only a small part of the overall organized events. Nonetheless, the Argentinian industry seems to be taking steps to develop a support system for enterprises interested in implementing the new technologies, and the initiative shows promise. If successful, it has the potential to be scaled up, perhaps by providing an online repository or a physical space to create a cooperative digital transformation entity that oversees the events, but also provides funding and laboratory space for industries.

In situations where resources are limited, initiatives like this could serve as a good starting point for the development of the XR ecosystem. Such initiatives do not require building laboratories and facilities, but exploit existing spaces and expertise in other institutions. Compared to accelerator-type facilities, they are less costly for the government, but still enable knowledge transfer to the private sector. This, in turn, also enhances technical competencies among Argentinian SMEs.

As the initiative is targeted to SMEs across all sectors, it has the potential to serve as an example for the development of XR in multiple ecosystems. This initiative could be particularly valuable for Europe in promoting XR technologies in ecosystems where their adoption as a productivity solution is relatively limited, such as agri-food, construction, and energy-intensive industries.³⁴⁷ These sectors would benefit greatly from participating in expert-led seminars and workshops, so that they could start adopting XR to see increased productivity and efficiency. For instance, in the construction sector, where XR has already been used in construction sites in the project and training phases, while in agri-food, XR could be helpful in monitoring warehouses from a distance.³⁴⁸ Additionally, XR can contribute to improved precision in manufacturing, particularly in quality control for energy-intensive industries,³⁴⁹ leading to fewer costs and reduced production times.

Case study #7: Electric South

Table 25. Overview of Electric South

Geographic area	Africa
Country	South Africa
Website (if available)	https://www.electricsouth.org/
Budget	Approx. €27.500 in public funding (overall budget unknown)

³⁴⁵ Full list available at <https://www.argentina.gob.ar/noticias/el-gobierno-aprobo-la-creacion-de-19-unidades-de-transformacion-digital-para-aumentar-la>

³⁴⁶ Universidad Nacional Mar del Plata - <https://www.mdp.edu.ar/utd/>, Universidad Nacional de Tierra del Fuego - <https://utd.untdf.edu.ar/>,

Universidad Nacional de Tucumán - <https://www.facet.unt.edu.ar/utd/sobre-nosotros/>, Universidad Nacional de Córdoba - <https://fcefy.unc.edu.ar/facultad/secretarias/extension/unidad-transformacion-digital/novedades-utd/sabias-que-somos-una-unidad-de-transformacion-digital-utd/>, Centro Tecnológico CIDETER - <https://cecma.com.ar/cideter-una-de-las-19-utd-seleccionada-para-aumentar-la-productividad/> and Centro Industrial Las Parejas - <http://centroindustrial.org/category/utd/>

³⁴⁷ See chapter 2.2 of this report.

³⁴⁸ Ibid.

³⁴⁹ Ibid.

Objectives and scope

Electric South is a non-profit company from South Africa, that over the years has been sponsored, among others, by the South African National Film and Video Foundation, as well as the Ford Foundation, the Bertha Foundation, Meta, Unity, the Mozilla Foundation, the British Council, Goethe Institut, Oculus, VR for Good, Big World Cinema, Blue Ice Docs, and SDK Digital Lab.³⁵⁰

The core of Electric South's work is the organisation and implementation of XR labs. During this work, Electric South acts as a film production studio, providing mentorship for emergent XR filmmakers, helping with production and post-production, and funding the best projects.³⁵¹ The films produced use XR, immersive technologies, and other emergent digital technologies. After production, the company provides exhibition opportunities and helps filmmakers build effective business models for the future. Interactive projects endorsed by the studio have reached prestigious international film festivals, such as Sundance Festival, IDFA (International Documentary Film Festival Amsterdam), the Venice Film Festival, and Tribeca Festival.³⁵²

Electric South has supported numerous festivals and organized many workshops and labs across Africa, with the intent to create a community of companies and individuals experimenting with emerging filmmaking technologies and innovative storytelling throughout the continent.³⁵³ Electric South was the organizer of Electric Africa (2020), an online free festival that featured 360 films exclusively and saw contributors from all over the Global South, including some contributions from South American countries. The event included a Metaverse Africa Meetup on VRchat and a closing night event.³⁵⁴ It was sponsored by South Africa's Department of Sports, Arts and Culture, the National Film and Video Foundation, the Bertha Foundation, the French Institute of South Africa, and LucidWeb.

As of April 2023, an open call for applications to the 'African XR Realities Lab' is active on the Electric South Website. The plan is to involve creators and XR experts in the creation of eight interactive storytelling prototypes using reality capture tools. This call sees the collaboration of Electric South with Meta.³⁵⁵ The company is also implementing a UNESCO-led initiative, 'World Heritage Futures Lab', through promoting the use of VR technologies to showcase World Heritage Sites in the region.³⁵⁶

The company was founded in 2015 and organizes at least one lab a year since 2016 (with the exception of 2020 which saw Electric Africa as a virtual alternative to in-person labs). In their early years of operation, Electric South's work focused on 360° technologies, which were more developed at the time. The operational focus of the organisation then gradually shifted to XR technologies, as they became more available.³⁵⁷

The bulk of funding received by Electric South comes from private sources, such as the Ford Foundation.³⁵⁸ However, some public funding has been allocated to certain projects, such as the pan-African new dimensions lab in 2022, which received approximately €25,000 from the South African National Film and Video Foundation, or Electric Africa, that saw a public contribution of around 50.000 ZAR (approx. €2,500).³⁵⁹ A possible reason why public funding has been comparatively scarce is that South Africa does not have a comprehensive policy plan to allocate funding to XR technologies; the funding allocated comes in fact from

³⁵⁰ Electric South, available at: <https://www.electricsouth.org/#supportedby>

³⁵¹ Electric South, available at: https://www.electricsouth.org/production_year/2021/

³⁵² Electric South, available at: <https://www.electricsouth.org/exhibitions/>

³⁵³ Electric South, available at: <https://www.electricsouth.org/workshops/>

³⁵⁴ Electric South, available at: <https://www.electricsouth.org/electric-africa/>

³⁵⁵ Electric South, available at: <https://www.electricsouth.org/open-call-for-the-african-xr-realities-lab/>

³⁵⁶ Electric South, available at: https://www.electricsouth.org/workshop_item/world-heritage-futures-lab/

³⁵⁷ Interview with Electric South representative, 2023 April 14

³⁵⁸ Ibid.

³⁵⁹ Ibid.

a 'special funding' cohort – rather than from the usual funding used by the National Film and Video Foundation for fiction and documentary projects.³⁶⁰

Assessing the impact at a global-level for the XR industry and EU strategic autonomy

As mentioned above, Electric South has successfully managed to reach the international exhibition scene with its films and immersive projects, and has established throughout the years numerous ties with international companies and organizations, like Meta. It has also succeeded in reaching many African countries with its workshops, which involved creators from South Africa, Zimbabwe, Botswana, Mauritius, Nigeria, Sudan, Kenya, and more.³⁶¹ Its goals of integrating African individuals and businesses involved in the XR storytelling sector seem, therefore, on the way to success. As explained by Antoinette Engel, producer at Electric South, the main challenges they have encountered with their organisation are a lack of infrastructure, such as low bandwidth connection across much of Africa, and difficulties in obtaining funding, since public funding is relatively scarce and private funding fluctuates.

Nevertheless, the scale of collaborations with Electric South is increasing, from national organizations to international giants, with their latest project partners being Meta and UNESCO. The last two years have also been particularly productive, with a higher than usual number of labs and initiatives carried out. The South African XR environment also seems to be growing, with public interest in XR technologies increasing and more exposition opportunities becoming available for Electric South to showcase their work.³⁶² There is, thus, potential for growth within the initiative in terms of interactions between the African XR storytelling environment and international companies and platforms, even though at the moment there are no concrete plans for scaling the initiative.³⁶³

Workshops created using Electric South as a model could be helpful in reducing societal barriers to XR adoption, as well as reducing reluctance within the industry towards XR uptake and application. A representative of Electric South identified societal barriers to XR adoption as the main barriers they are aiming to tackle. Indeed, helping XR artists grow and present their work to wider audiences could help an increasing number of artists to take up interest in these new technologies. The hope in doing this is also that more and more industries outside the creative technologies sector would eventually respond to the growing market opportunities.³⁶⁴

The European creative sector is already looking at XR technologies to develop innovative instruments for storytelling,³⁶⁵ but it would benefit from an organization, such as Electric South. The presence of an overarching organization able to harness talent and provide funding, assistance, and networking opportunities could help the European cultural and creative ecosystem as Electric South did in South Africa and the African region in terms of enhanced collaborations and interactions within the ecosystem, and in the international scene. A similar European endeavour could possibly increase the competitiveness of the European XR industry on a global scale, an outcome that would be welcome by the European creative sector.³⁶⁶ It could also increase the productivity of the ecosystem, as more creators would receive the funding, they need to start experimenting with XR technologies.

³⁶⁰ Ibid.

³⁶¹ Electric South, available at: <https://www.electricsouth.org/workshops/>

³⁶² Interview with Electric South representative, 2023 April 14

³⁶³ Ibid.

³⁶⁴ Ibid.

³⁶⁵ See section 2.2 of this report.

³⁶⁶ See section 2.4 of this report.

More cohesion in the ecosystem would also be instrumental to improve existing software and hardware used for creative production, thanks to improved communication within the European XR environment. Moreover, a pan-European production studio that also offers business guidance would also help improve the XR industry's business models, which have been found to be somewhat weak.³⁶⁷ A concerted effort in media production could also help reduce the high European market fragmentation of XR application in the creative industries,³⁶⁸ like Electric South is doing for Africa. Similarly, the unified character of the platform could also help to open up new much needed marketing opportunities for the ecosystem,³⁶⁹ under the guidance of the studio, perhaps based on XR technology itself.

Case study #8: RAEscolas

Table 26. Overview of RAEscolas

Geographic area	South America
Country	Brazil
Website (if available)	https://raescolas.ufsc.br/en and https://www.gov.br/cnpq/pt-br/assuntos/noticias/atualidades/projeto-disponibiliza-ferramenta-gratuita-de-realidade-aumentada-nas-escolas
Budget	Unknown

Objectives and scope

'RAEscolas – Virtual Reality in Schools' is an initiative, executed by LabTeC UFSC (Laboratory of Computational Technology at the University of Santa Catarina - UFSC), in cooperation with the Pro-Rector of Extension at UFSC and the Open University of London, and funded by the Ministry of Science, Technology, and Innovation of Brazil. In particular, the government funding comes from the General Coordination for the Promotion of Science Teaching (CGPE), an agency created with the aim to 'develop innovative programs, projects and actions in basic education in Brazil, encourage public schools to innovate in education and encourage students to dedicate themselves to scientific and technological research, and to develop their potential in the field of science in Brazil.'³⁷⁰

RAEscolas focuses on creating educational artefacts in the form of AR flashcards, 3D models, and virtual images that can be augmented and explored in 3D with multiple devices, such as VR visors, smartphones, and tablets.³⁷¹ The artefacts are stored in an online repository according to their subject (physics, chemistry, astronomy, human body, environment, etc.). The repository can be downloaded freely from the RAEscolas website, together with Zappar application, which is required to access the augmented reality component.³⁷² The materials are designed for use in primary and secondary education and includes training for teachers on the use of technology in the classroom.³⁷³

The initiative was presented, already operational and ready for use in schools, on October 17th, 2022, at the 19th National Science and Technology Week (SNCT).³⁷⁴

No publicly available information was obtained on the overall budget allocated for the initiative.

³⁶⁷ Ibid.

³⁶⁸ Ibid.

³⁶⁹ Ibid.

³⁷⁰ Ministry of Science, Technology and Innovation, available at: <https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/cgpe>

³⁷¹ RAEscolas, available at: <https://raescolas.ufsc.br/en/#repository>

³⁷² RAEscolas, available at: <https://raescolas.ufsc.br/en/#zappar>

³⁷³ National Council for Scientific and Technological Development, available at: <https://www.gov.br/cnpq/pt-br/assuntos/noticias/atualidades/projeto-disponibiliza-ferramenta-gratuita-de-realidade-aumentada-nas-escolas>

³⁷⁴ Ibid.

Assessing the impact at a global level for the XR industry and EU strategic autonomy

The RAEscolas initiative has successfully developed a comprehensive database of AR artefacts. However, there is little evidence of the repository being used in schools. The project has also received minimal press coverage. Newspaper Tribuna do Pampa suggests that RAEscolas is being implemented in all schools within the Candiota municipality.³⁷⁵ The project's social media also indicates some schools engaging with the initiative, but it is not possible to quantify them or evaluate their experience from the publicly available data. Overall, it appears that the project has not so far generated enough attention to reach its full potential, as it needs to be implemented by more schools to be considered successful.

The potential of RAEscolas is significant. It offers an opportunity for the adoption of AR technologies in public education, overcoming an important infrastructural barrier to AR implementation by eliminating the need for specialized hardware. The platform only requires the installation of a freely available app, making the platform easy to use and cost-free. The app, developed by Zappar, is a simulation software that is freely available worldwide and runs on most Apple or Android devices.

The ease of use of mobile AR applications has the potential for adoption in Europe, as well. While it has already been applied in many instances in the tourism sector (tour-guiding technology), and in the retail sector (virtual try-ons),³⁷⁶ it can also serve as an alternative where public schools, or institutions of the social ecosystem, might not have the budget for costly AR educational programs. This would increase the effectiveness of learning without having to bear the cost of visors or sensors. Additionally, the initiative would also eliminate the need for institutions to cooperate with (and pay for) external personnel, as the initiative already provides quick and easy training resources for teachers who want to implement RAEscolas in their classrooms.

³⁷⁵ Tribuna do Pampa, available at: <https://www.tribunadopampa.com.br/projeto-realidade-aumentada-sera-implantado-em-candiota/>

³⁷⁶ See section 2.2 of this report.

Annex 7: Workshop report

Date: June 15, 2023

Time: 09:30 – 12:00 CET

Place: Virtual meeting (MS Teams)

Table 27. Overview of workshop participants

Participant	Organisation
Alain Gallez	stereopsia, XR4Europe
Anne Bajart	European Commission, DG CNECT
Brian Waterfield	BWC/Metaverse Alliance UK
Lukas Heiduk	Statista
Popescu Andreea	European Commission, DG CNECT
Thomas De Bruyne	Deloitte
Pol Diestre	Ecorys
Marco Sacco	EUROXR - CNR-STIIMA
Marta Palau Franco	European Commission, DG CNECT
Andrea Bravo	Metaverse Data & Ethics
Cederik Haverbeke	XR Valley
Elena Bascone	XR4Europe
Eusebio Felguera Garrido	Telefonica S.A.
Isabel De Peuter-Rutten	Euromersive
Vishal Reddy	Immersion Ready
Thomas Alsop	Statista
Krista Jäntti	EventuallyXR
Sylvie Dijkstra-Soudarissanane	TNO
Patrick Bourdot	CNRS - EuroXR
Ricard Gras	Captic GmbH
Ivan Rajkovic	SpectreXR
Iuliana Moje	Euromersive
Sönke Kirchhof	INVR.SPACE - XR4EU
Albena Dimitrova Mihovska	Euromersive

Participant	Organisation
Marta Materska-Samek	EIT Culture & Creativity - UNA Europa - Jagiellonian University

Introduction

This document presents the views expressed by workshop participants and should not be considered as conclusions or findings of the study.

- Anne Bajart (DG-CNECT) opened the discussion by marking that this study will feed into the recent virtual worlds initiative, and that this study is very timely in terms of recommendations and next steps.
- The study team presented the aims and methodology of the study, as well as key findings in terms of the barriers to adoption and development of XR.

Summary of discussions

Initial comments on barriers as a whole:

- Participants considered it to be potentially useful to 'rank' the barriers by persistence/importance to identify which ones need more (timely) intervention.
- The participants highlighted the importance of European infrastructure for technology development (e.g., connectivity).
- The importance of involving people in technological advancements and the need to involve more potential users for technology to work was also highlighted.
- Participants remarked that the EU does have competences and resources and has produced great actors in XR (Unity, SpectreXR, Lynx, among others). However, the EU has the disadvantage of being very dispersed compared to other global players.
- Some participants were of the view that the EU needs a 'Marshall plan' for XR technology, involving existing providers, to make EU actors competitive in the global market and not just 'followers' of foreign product launches.

Panel discussion one: 'technological, financial, market-related barriers'

Fragmented EU industry and the need for industry networking

- EU industry is fragmented – XR companies in the EU are usually small and they are all trying to make their own breakthroughs. Different MSs have different expertise and specialisations. Workshop participants suggested the following to counter this:
 - Europe does not have one big community, but does have many smaller communities. Instead of creating new ones, creating a **platform** would create synergies for business and research.
 - Helping each other (as opposed to competing) would be beneficial for all actors. This could be facilitated through **community-building initiatives**.
 - There is the necessity for Europe to adopt a proactive and ambitious approach, akin to the creation of Airbus or Galileo. Participants suggested

focusing on creating synergies among existing SMEs in the XR technology space and corporations developing applications. The need for a collaborative networking system was emphasised.

- Regarding **SMEs**, it is important to structure their cooperation. Networking requires a large structure and Europe's SMEs do not have the capacity to create these networks on their own.
- In Europe, there is a need for better opportunities to **deploy and invent**. It is necessary to provide the conditions for instant creation. For example, events similar to Hackathon but on a larger scale could bring people together, and also create opportunities to solve hardware challenges.
- The EU could promote some sort of smart specialisation per hub/country so that duplication of efforts is avoided.

Ethics and regulation

- While Europe does not have many big ventures there are strong in **ethics** within the **EU**. There is potential for the EU to become a leader in ensuring safe XR.
- The EU needs to be able to target the global market. To facilitate this, the EU must decide on a **unifying active policy** for XR, finding a balance between existing XR technologies and new applications.
- XR should not be overregulated by the EU. For example, concerning issues of interoperability, this is a question more relevant to big tech and not the EU.
- XR technology is not the product, it is a technology. It is fundamental that **ethics are designed for technology** and not for a product. Apple is one good example of this and is part of their success.
- **Ethics** are important, but also act as a barrier. For example, less data privacy in China means more data for deep machine learning. The big issue is how to manage ethics and the **limitations** they create. As of now, ethical standards can be limiting **research**. Europe will simultaneously need to protect users' data and also use that data during research activities.

Investment needs

- There is big discussion around AI and cloud technologies (according to one participant in the Netherlands). Which **investments** could the EU make to amplify strengths? Data security, cyber security, and storage are relevant discussion issues in the context not only of XR but also of AI.
- Start-ups need more funding. A beneficial possibility would be the potential to create an **investment plan** that would also integrate other technologies. XR alone is, at present, too small a focus for a significant grant.
- Grants are not sufficient to create a big technology company to play in the **global market** (rather, they are good for SMEs).
- **Framing investment** in terms of interface and user content, and linking XR technology to other technology applications, would change the conversation around XR and attract more funding. Discussion should be about *what XR can do* rather than just about the technology itself.

- **Terminology problem** – confusion with other technologies and possibilities: e.g., confusion between XR and virtual worlds.
- There should be consideration of how to speak about XR, using a **neutral term** that does not favour any company. A suggestion is ‘spatial computing’. This term encapsulates much more than just XR by itself.
- What the Commission uses now is ‘**Virtual Worlds**’. However, Virtual Worlds do not semantically target Augmented Reality, although the Commission has this in mind as well, and that is a problem.
- Of key importance is educating policymakers, stakeholders, and people in various capital cities about the new technologies. This education should also encompass the correct use of terminology related to these technologies.

Panel discussion two: ‘societal, legal, ethical barriers’

Societal barriers to development and adoption of XR solutions

- Europe needs to orchestrate a common effort to organise events that engage the public (e.g., making people try out XR first hand), to solve users’ resistance to XR technology. A European effort could be more effective than fragmented groups of enthusiasts or associations. EU could provide common guidance and guide an awareness.
- Professionals should be encouraged to understand how XR can be useful to them. The EU needs to build ethical principles around professionals, who will then develop consumer-friendly platforms and products, and ‘evangelise’ XR to a wider audience.
- Potential solutions for public resistance to XR technologies should be free and accessible to everyone. Care should be taken not to create a class divide – no one must be left out (e.g., rural areas still struggle with internet connection).
- A citizens’ panel could be useful to research potential users’ concerns in order to understand what is hindering the success of the European XR industry the most.

The central role of education systems in addressing societal barriers

- Educational institutions should do more to introduce new technologies to children from a young age.
- At present, European universities are developing products that either never make it to market, or are bought by foreign corporations. It should be ensured that it is easier for products developed at European universities to get to market.
- It is essential that research in Europe happens in sync (e.g., that two or more universities do not waste resources on developing similar projects). Universities should work with each other, sharing expertise instead of competing. The present system puts them in competition to get funds/students. **Associations** can help resolve this issue, acting as a vessel to share expertise between universities and the whole ecosystem.

Legislative barriers

- The EU has an opportunity to look at global technology opposed to looking at it through a national lens, **including non-EU countries** in the discussion as well. Scandinavia is showing a lot of promise technologically.
 - The US and China have an advantage over the EU, as they experience less fragmentation.
 - It would be beneficial to build a community that encompasses Europe beyond the EU. Virtual worlds in Europe could be very functional in bringing more of Europe together.
- The legal framework in Europe needs to be analysed to see if it is still relevant in the face of AI development. Professionals need to come together to assess what needs to be changed.
- There is a need for a **European starting point for legislation** around common values to regulate the XR industry (e.g., data privacy, accessibility, user protection). It is not feasible to create common legislation from each Member State – it must be the opposite (MS legislate starting from a common European understanding).
 - There is an opportunity to create a nimble legal framework that puts users first. It is not realistic to unify all XR legislation, but creating a comprehensive legal framework that puts users first would give Europe a competitive advantage worldwide, as it has been the case in other areas (e.g., GDPR).
 - The problem with a GDPR-like legal framework would be that it would only work in Europe – the danger is that it would hinder competitiveness globally if the industry is overregulated. For example, it is important to monitor issues related to health and safety, but the potential of risks being present in those areas should not prevent innovation.
 - A unified legal framework can take European values as a starting point to unify the existing and potential user base.

Ethical issues

- There are threats related to **health and safety**. Sometimes the threats are legitimate, but users and citizens may overperceive danger in the case that they get information via non-institutional sources (e.g., mainstream media that know very little about XR).

The needs of businesses

- The many existing initiatives should be united under a more official umbrella, like an overarching **European consortium** of the main actors in the field, sponsored by the EU, in which non-European actors can also participate. Such initiatives already exist, but mainly outside of Europe.
- Companies need more **funds for innovation** (especially in seed and pre-seed stages), to prevent them from being acquired by tech giants too soon. Requirements for startup funding are often too strict. Start-ups often do not have the resources or knowledge on how to apply.
- SMEs need to have a **'one-stop-shop'** for all their legal and operational problems that is standardised, recognised, and European.

- **University-born startups** should get more continued support, so that they have other options available other than being bought by bigger corporations.

Plenary discussion

Summary of breakout rooms discussions

The panel moderators summarised the two discussions for the convenience of all participants.

Concluding discussion: last remarks

- Apple Vision Pro launch could be viewed for inspiration on how to create 'hype' among users. There is a real interest in XR solutions, but the EU needs well-organised awareness-building events that engage communities.
- Igniting the free market is important to make sure that business leaders engage in experimentation. It is also equally important to ensure that the grant system does not hinder those that are willing to experiment.
- Europe needs common standards and an open-minded approach to allow innovation to flourish.
- It is clear that there is a strong desire to develop a 'community of communities' in the XR field.
- There is a huge potential in the European user base, which is yet to be mobilised.
- Discussions on XR are inherently connected to the broader issues of the competitiveness of European tech sector.
- XR is only as powerful as the context in which it operates. It is inherently linked to AI, connectivity, cloud, blockchain, and other technologies.

Annex 8: Exemplary financing cases of EU companies

This annex shows examples of the recent financing success stories for EU companies more widely in various ecosystems. The data presented below relies on Crunchbase and Dealroom data. Types of funding mentioned below are understood as follows:

- **Pre-seed:** Earliest stage of funding; pre-institutional seed funding round that either has no institutional investors or is a very low amount, often below €130,000. The most common pre-seed funders are the founders themselves, as well as close friends, supporters and family.
- **Seed:** Among the first rounds of funding; first official equity funding stage, generally, while the company is young and working to gain traction; generally ranges between €8,000 and €1.8 million.
- **Early-stage VC:** Series A and B; once a business has developed a track record (e.g., established user base, consistent revenue figures), past the development stage; generally between €1 million and €30,000.
- **Late-stage VC:** Additional larger funding for already established and successful businesses (e.g., develop new products, access new markets); generally over €10 million.
- **Private equity:** Led by a private equity firm or a hedge fund and is a late stage round; less risky investment as the company is more firmly established; rounds typically upwards of €45 million.
- **Debt:** An investor lends money to a company, and the company promises to repay the debt with added interest.
- **Convertible note:** 'In-between' funding round to help companies hold over until they want to raise their next round of funding.

Aerospace and defence



VRgineers³⁷⁷ (11-50 employees), based in Prague (CZ), founded in 2017: delivers next-generation virtual and mixed reality pilot training systems for professional and military clients. VRgineers' pilot training solution includes portable trainers ready to be packed and taken on missions; reconfigurable classroom simulators that support almost all platforms; and custom 1:1 simulators that are built specifically for any type of helicopter, jetfighter, or airliner, and include a fully functional cockpit replica.³⁷⁸

- Total funding raised (as of 2015): €6,249,693
- Last funding type: early-stage VC

Construction



Nodalview³⁷⁹ (51-200 employees), based in Brussels (BE), founded in 2016: sales and marketing platform built for the real estate industry. It has been adopted by over 10,000 real estate agents to date. The platform enables its customers to shoot and build professional quality pictures, 360° virtual tours, and videos of properties, as visual experiences become ever more important in the real estate marketing value chain. It has raised €4 million in a

³⁷⁷ Website available [here](#)

³⁷⁸ Vrgineers (2023), available [here](#)

³⁷⁹ Website available [here](#)

new investment round aimed at further expanding in its core markets, as well as broadening its product within the real estate value chain. Nodalview's own research revealed that 88% of properties listed by agents on the main property portals in France and Belgium are not utilising buyer-friendly tech beyond that of the age-old process of traditional photography.³⁸⁰

- Total funding raised (as of 2015): ~€9,700,000
- Last funding amount: €4,000,000 (in December 2022)
- Last funding type: early-stage VC

Cultural and creative

 LYFTA³⁸¹ (11-50 employees) based in Helsinki (FI), founded in 2016: platform where teachers can find engaging and immersive content to introduce and delve into complex topics. Lyfta designs and produces high-quality, immersive learning environments, using virtual reality & augmented reality (VR&AR), and interactive 360° storytelling. The platform is cross-curricular, the content and resources are ideal for teaching a range of subjects including literacy, personal, social and health education (PSHE), relationships and sex education (RSE), geography, citizenship, physical education (PE), science, religious education (RE), design & technology, and the United Nations Sustainable Development Goals (SDGs). Lyfta is currently used in 700 schools with over 2,500 teachers in the UK, US, and Finland.³⁸²

- Total funding raised (as of 2015): €5,534,326
- Last funding amount: €2,764,425

Digital

 DIDIMO³⁸³ (11-50 employees) based in Porto (PT), founded in 2016: a virtual human technology solution provider, providing automated solutions for the generation of real-time digital human avatars. The platform allows companies, software developers, collaboration platforms, and app builders to integrate a solution for generating user characters in their own software solutions. EU support under the SME instrument helped the company establish their ethics and responsibility policies, which cannot be ignored when creating a technology that builds digital humans. The grant also helped the technical team in the development of Didimo's core patented API technology, retail, and mobile product.³⁸⁴

- Total funding raised (as of 2015): €14,850,000
- Last funding amount: €6,665,800
- Last funding type: Early-stage Venture, Series A

Electronics

 Varjo³⁸⁵ (101-250 employees) based in Helsinki (FI), founded in 2016: provider of professional-grade VR/XR hardware and software, producing high-tech VR headsets and solutions for the enterprise market across various industries for different purposes, such as

³⁸⁰ TechEu (2022), available [here](#)

³⁸¹ Website available [here](#)

³⁸² HundrED (2020), available [here](#)

³⁸³ Website available [here](#)

³⁸⁴ CORDIS, available [here](#)

³⁸⁵ Website available [here](#)

training and simulation, design and engineering, and research. Recently Varjo secured €40 million in new funding for its R&D cloud services, namely Varjo Reality Cloud, the company's XR streaming platform. The new capital will help the company continue to scale its software and hardware offerings across new enterprise verticals, such as design & manufacturing, engineering, education, and healthcare.

- Total funding raised (as of 2015): €150,000,000
- Last funding amount: €40,000,000
- Last funding type: Series D³⁸⁶

Healthcare



Oncomfort³⁸⁷ (11-50 employees) based Brussels (BE), founded in 2015: offering Digital Sedation solution providing relief for patients' pain and anxiety through treatment with sessions of therapeutic Virtual Reality. It has raised €10 million in Series A funding to bolster its digital therapy solutions and accelerate its international expansion.³⁸⁸ The company stated that, since the launch its 'Sedakit' for Digital Sedation in Benelux and France in June 2019, over 30,000 patients have been treated and have had their pain and anxiety relieved before, during, and after interventions in many clinical fields, such as anesthesia, oncology, interventional radiology, and cardiology, as well as pediatrics.³⁸⁹

- Total funding raised (as of 2015): €13,624,814
- Last funding amount: €10,000,000
- Last funding type: early-stage VC – Series A

Mobility, transport and automotive

BASEMARK

Basemark³⁹⁰ (51-100 employees), based in Helsinki (FI), founded in 2015: provider of software and tooling solutions for advanced automotive AR application development - Video AR, AR Navigation, AR HUDs, and AR Clusters. Augmented reality-powered information displays help the driver with vehicle interaction and to be more aware of their surroundings.³⁹¹

- Total funding raised (as of 2015): €10,545,000
- Last funding amount: €7,000,000 (in 2020)
- Last funding type: early-stage VC- Series A

Retail

INVRSION³⁹² (11-50 employees), based in Milano (IT), founded in 2015: develops ultra-realistic 6DOF VR simulation with focus on retail and 3D product digitisation. Specialised in the virtualisation of spaces and the digitisation of references for the retail sector, in order to lower costs, and, at the same time, speed up the execution of in-store

³⁸⁶ Serie D is a late-stage VC round, typically consisting of larger funding for already established and successful businesses, used for expansion, acquisitions or preparing for an IPO.

³⁸⁷ Website available [here](#)

³⁸⁸ TechEU (2020), available [here](#)

³⁸⁹ Mobihealthnews (2020), available [here](#)

³⁹⁰ Website available [here](#)

³⁹¹ TechCrunch (2022), available [here](#)

³⁹² Website available [here](#)

activities, optimising the negotiation processes between brands and retailers in the fields of trade marketing, consumer research, staff training, and store design and remodelling.

- Total funding raised (as of 2015): €6,475,000
- Last funding amount: €2,000,000
- Last funding type: Seed

Textile and fashion



ZERO10³⁹³ (11-50 employees), based in Limassol (CY), founded in 2020: AR-fashion platform offering cutting-edge tech options for companies joining the online marketplace. The digital fashion hub enables designers, brands, and users to not only wear, but also create virtual clothes for augmented reality. ZERO10 AR Studio will allow creators to transform their designs into augmented reality through user-friendly and free to use design tools.

- Total funding raised (as of 2015): €3,680,000
- Last funding amount: €1,398,525
- Last funding type: Seed

Tourism



SmartGuide³⁹⁴ (11-50 employees), based in Prague (CZ), founded in 2018: global platform for digital guides that turns every phone into a personal guide and every tourist into an explorer, using audio, geolocation, and Augmented Reality, like a live guide. SmartGuide hosts a collection of tours which tourists can access from the app home page or via invitation codes. Tours are downloaded to a mobile device, and can then be enjoyed anytime, either on-location, or as virtual guides from home.

- Total funding raised (as of 2015): €2,678,018
- Last funding amount: €1,000,000
- Last funding type: Seed

³⁹³ Website available [here](#)

³⁹⁴ Website available [here](#)

Annex 9: Suggested areas for further research

In addition to recommendations, the report also includes suggestions for areas worth exploring in terms of the socio-economic effects of the adoption of XR technologies across industries, as well as the appropriate policy responses to them. These suggestions stem from stakeholder consultations (i.e. 49 interviews, a Delphi survey of 109 experts), desk research (i.e. collection of background information on the XR industry in Europe across different ecosystems, identification of good practices, analysing emerging technologies relevant to XR, mapping virtual worlds), and attendance of XR-related events. However, given the limited evidence base for each suggestion, these findings did not lead to actionable recommendations, but constitute important “weak signals” and warrant further exploration.

Research on potential negative effects of XR

There is still insufficient evidence on the potential negative effects of XR technologies, and how to alleviate or accommodate them. This is due to the novelty of XR technologies and the complexity of potential negative effects. A good understanding of potential negative effects is needed to establish clear behavioural guidelines to ensure XR technologies remain accessible, secure, and safe.

Relevant topics for further research in this area could include physical health effects as well as mental and psychological ones. Physical health effects could include considerations regarding the safety of users in the space, impacts of use of XR in the visual and/or neurological system, impacts on child growth and development, indications on the duration of safe use, potential changes in lifestyle, and amount of physical activity, etc. Regarding mental and psychological effects, further research could cover the following, among others:

- ethical considerations for using XR
- the psychological effects of long-term immersion (differentiating between different age groups)
- the effects of XR on human cognitive processes
- the capabilities of XR to alter perceptions and personal identities
- how to reduce cybersickness
- how to improve accessibility for vulnerable people
- how to maintain moral subjectivity
- the impact of XR on real-life social relationships
- the use and misuse of personal data in relation to XR interactions; how to use XR for promoting empathy

In addition, assessments of technologies, and their effects, are based on well-established methods. However, with the introduction of new technologies and the changes they bring, it is important to consider whether the methods of assessment also need updating. Hence, the research should also investigate new ways of measuring the impact of new technologies on different aspects of human life.

Research on environmental impact of XR

XR applications have the potential to improve the environmental sustainability of companies and households, by conducting activities in a virtual setting, which would otherwise either require travelling or physical infrastructure, use of materials, creation of physical prototypes, etc. However, XR applications also require high computational and thus electric power, and natural resources for hardware production, and XR hardware is characterized by not naturally bounded demand, meaning that there is a continuous demand for product improvements. Therefore, there are both negative and potentially positive environmental impacts through the deployment of XR technologies.

Gaining an enhanced understanding through measurement, or estimation, of those impacts would help identify areas where the XR industry could avoid mistakes done in the development of other technologies, and reduce any negative environmental impacts. In addition, by understanding the net impact of specific applications and use cases, those with the highest potential for a positive environmental impact could be promoted.

XR and the digital divide

Similar to environmental sustainability, XR could close, or widen, the digital divide, depending on how it is deployed. For instance, XR could offer unique inclusiveness opportunities, such as for people in remote areas, people with disabilities, elderly people, etc. However, the cost of the hardware and deployment of an XR solution may hamper the inclusion of low income or not digitally savvy people. In a similar way, certain businesses and industrial ecosystems being more prone to new technologies may get most of the benefits from the uptake of XR solutions, compared to others. Monitoring the impact of XR technologies on the digital divide, and ensuring that no group of society is being excluded from the potential benefits from their use, is essential.

Continuous monitoring of XR market

The landscape of XR is fast-paced, continuously evolving, and innovating as new players (including tech giants) are entering the market and technological innovations occur. While currently there does not seem to be a need for immediate legislative action, specifically targeting XR, due to the rapidly changing landscape, new challenges may arise. Continuous monitoring of the XR market both in Europe and abroad is essential in identifying issues and challenges that are not (fully) addressed by the current legal framework, or the need for harmonisation among Member States.

Improving technological infrastructure relevant for connectivity

Infrastructure was highlighted to be a key component that facilitates the use of XR solutions. This includes connectivity as well as cloud and edge computing, which can deliver low-latency solutions and better device performance and capabilities. Cloud infrastructure also reduces the burden on devices to manage data, which can instead be offloaded and computed elsewhere, opening up opportunities for more lightweight and ergonomic devices. In addition, blockchain technology could be an essential facilitator of trust and security within XR and has the potential to increase the reliability of interactions in virtual worlds. Finally, artificial intelligence is important across several technologies to provide computational power, including rendering and big data management, and make real-time automated decisions, which facilitate accurate and efficient XR integration. With well-established infrastructure, the collaboration and interoperability of technologies have the potential to build engaging and seamless XR experiences, which also have the capabilities to manage the computation demands of XR applications, and in particular, virtual worlds, while also ensuring greater comfort, reliability, and trust for users.

Facilitating developments in XR-related technology areas

Developments in metamaterials, graphene, and advanced semiconductor chips can contribute to the advancement of XR hardware and wearables. They offer the potential for lighter components and advanced visual experiences, reducing experiences of cybersickness or discomfort. Similarly, developments in novel display technologies and optics and sensing can deliver more immersive XR experiences, by providing realistic visual or physical stimuli and feedback.

Future research and development activities could focus on the application of metamaterials (including graphene), advanced semiconductor chips, display technologies and optics, and sensing to make XR devices lighter, ergonomic, and more powerful, making the experience in using them more realistic. Successful research and take up of its results could result in new European products that could potentially compete on a global market.

Annex 10: Presentation event report

Date: 19 September, 2023

Time: 9.30 – 11.00 (CET)

Place: Virtual meeting on Microsoft Teams

Table 28. Overview of presentation participants

Participant	Organisation
Tunde Levy	European Commission, DG CNECT
Andreea Popescu	European Commission, DG CNECT
Marta Palau Franco	European Commission, DG CNECT
Christoph Runde	Virtual Dimension Center w.V.
Bergur Thormundsson	Statista
Fabien Eyssartier	Unknown (freelance)
Timothy Owens	Statista
Zaneta Kubic	Jagiellonian University
Alanna Koh	Queensland XR Hub
Alexandra Borgeaud	Statista
Andrew Perkis	NTNU
Brian Waterfield	UK Metaverse Alliance
Kaba Barsch	Statista
Marta Materska- Samek	EIT Culture & Creativity - UNA Europa - Jagiellonian University
Ricard Gras	Captic
Thomas Alsop	Statista
Tracey Swales	Portable Kingdom Ltd
Valerie Riffaud Cangelosi	Reapse Consulting
Ilana Kunkel	Global Counsel
Ahmed Sherif	Unknown
Lionel Sujay Vailshery	Statista
Schreer Oliver	Fraunhofer Heinrich-Hertz-Institut
Krista Janti	Eventually XR
Patrick Grady	Metaverse EU
Albena Dimitrova Mihovska	Euromersive

Astrid Kahmke	Ionda GmbH
Nicolas van de Kerkhof	EIT Health
Francois Bouille	Euromersive
David Nahon	Dassault Systèmes
Luis Martins	APDC
Alexandre Bouchet	CLARTE
Jan Kamphuis	Simultria

Introduction

This document presents the views expressed by workshop participants during the discussions and should not be considered as conclusions of the study.

- Andreea Popescu (DG-CNECT) opened the discussion by marking that this study will feed into the recent Web 4.0 and virtual worlds initiative, which aims to prepare Europe for the Metaverse through a series of concerted policy actions, particularly those aimed at the development of the XR industry.
- The study team presented the aims, methodology and key findings of the study.

Summary of discussions

Intellectual property issues in the XR ecosystem

- It is now possible to generate 3D (XR) content with prompts, images, videos; better IP protection is needed throughout Europe.
- There should be a European initiative for IP in XR/ AI, like there is one in other countries (including the US). We need a standalone effort to tackle these legal challenges – this study did not cover this area.
- There are fears that the European XR technology sectors will sell-out to overseas, because better IP protection offers third countries a competitive advantage.

Definition of ‘virtual worlds’

- Virtual worlds are persistent, immersive environments, based on technologies including 3D and XR. These immersive environments make it possible to blend physical and digital worlds in real time, for a variety of purposes, such as designing, making simulations, collaborating, learning, socialising, carrying out transactions, or providing entertainment.
- The study used the term ‘virtual worlds’ as an umbrella term for all those spaces where users can interact virtually. The study focus was on zero-distance, for facilitation of interactions within the virtual space.

Evolution of barriers and challenges identified in the study

- Many issues are recurring, and it is important to monitor their yearly evolution. Some changes are visible, however; technology seems to be perceived less as a barrier by stakeholders. XR technology has become more affordable and common. Financing and funding challenges have also evolved – there are more funding opportunities and the challenge moved to funding scaling-up efforts, rather than finding funding for early stages and/or R&D.
- At present, there is a lot of funding for startups, comparatively to past years, but not for the community as a whole. Many XR companies have only benefitted from funding in their beginnings, but it is in later stages that they would need the most support, because the market is not yet mature. We also need to keep in mind that support is also needed for longer-standing XR companies, because lack of access to funding is hindering their possibility to grow.
- Of course, some challenges have mostly not changed, among those are fundamental legal issues and market fragmentation.
- We are also facing new challenges, which if resolved could give Europe a competitive advantage. For instance, tackling inclusivity and marginalisation are crucial to the European ecosystem.

Next steps at EU level

- The recommendations presented in this study, and other findings from other studies and workshops, intersect with each other. All those points are echoed in a recently launched communication by the EU³⁹⁵. The actions that are proposed are quite relevant to the concerns of the XR ecosystem, and the Commission is now working on those actions.
- By 2030, the co-funded and co-programmed European Partnerships under the Second Horizon Europe Strategic Plan³⁹⁶ will have helped developing virtual worlds and metaverses that:
 - are open and interoperable, based on widely accepted standards, preventing that only a few companies control them;
 - adequately feed the supply and demand ecosystem so that the EU can play a leading role in developing the future virtual worlds;
 - respect European rules (such as the General Data Protection Regulation, EU competition law or the EU labour law acquis) and values, in line with the Declaration on Digital Rights and Principles (human-centric, inclusive, trustworthy, safe and ethical,
 - offer significant business opportunities and new avenues for individual and collective creativity, arts and culture; and
 - focus on industrial and commercial applications and societal challenges such as the green and digital transition, the future of labour markets, smart cities, education and healthcare.

³⁹⁵ Communication available at: https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-strategic-plan-2025-2027-analysis-now-public-2023-05-25_en

³⁹⁶ Full analysis available at: https://research-and-innovation.ec.europa.eu/system/files/2023-07/ec_rtd_candidate-list-european-partnerships.pdf

Interoperability and standards for user safety

- Some type of coordination at the EU level is certainly needed – perhaps an overarching structure or association – to ensure interoperability and standards for safety. It is crucial to have active participation and willingness of the XR industry to join in and coordinate any possible efforts. But the study is not addressing this, because these problems go beyond XR – interoperability struggles are common to many technologies.
- Standardisation is fundamental. Usually, it is driven by large companies with sufficient resources. The Commission, in this case, has the opportunity to ensure that standardisation efforts come from the bottom-up, rather than being dictated by a few big tech giants. The EU needs to engage with the grassroots and create standards that work for everyone.

Agility of the EU Commission in tackling ecosystem issues

- The Commission now has quite a strong framework (e.g., the GDPR) and could be flexible enough to advance towards greater European competitiveness. However, fragmentation of the ecosystem is a major issue. In fact, all the issues mentioned need to be approached coherently, and EU efforts aim at this coherence.
- On interoperability, there is an ongoing specific action in the development of standards, involving all enabling technologies. This action is hoped to bring concrete results.

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