EUROPEAN
COMMISSION

Strasbourg, 11.7.2023
SWD(2023) 250 final

PART 1/2

**COMMISSION STAFF WORKING DOCUMENT**
***Accompanying the document***

**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

{COM(2023) 442 final}

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# 1 INTRODUCTION

This Staff Working Document (SWD) accompanies the Communication "***An EU initiative on web 4.0 and virtual worlds: a head start in the next technological transition***".

It is a factual and informative document that provides further information and insights on the main aspects of the Communication, including stakeholders' views, technology, market trends and an overview of relevant existing legislation impacting Web 4.0 and virtual worlds.

The Communication and its accompanying SWD build on the digital transformation of our economy and society that is now at the heart of the priorities of the European Union. These priorities are further reflected in the ambitious objectives and targets of the Digital Decade policy programme[1] which, together with the European Declaration on Digital Rights and Principles[2], sets the path towards a human-centred, sustainable and prosperous digital future. At the same time, the further development of Web 3.0 and its transition towards Web 4.0 and virtual worlds constitutes a major technological transition bringing a seamlessly interconnected, intelligent and immersive world that will profoundly impact the daily social and professional life of people.

This SWD starts by presenting the findings by the European Commission in view of the Virtual World and Web 4.0 initiative announced by President von de Leyen on the 14th of September 2022. It includes the results derived from consulting with relevant stakeholders, studying the global market and technological trends and mapping the relevant existing legislation.

The SWD also presents the main challenges in this transition from Web 2.0 to Web 3.0 and to Web 4.0, where technologies such as the internet of things, artificial intelligence and extended reality will allow a seamless integration between digital and real objects and environments, and more natural and enhanced interactions between humans and machines.

Virtual worlds are an important part of the further development of Web 3.0 and its transition to Web 4.0. Persistent, immersive digital environments allow the blending of physical and digital worlds in real-time. The SWD provides, therefore, insights on how virtual worlds are already opening a wide range of opportunities in many societal, industrial and public sectors and how these are technically, economically and socially feasible now thanks to core technologies readiness and an improved connectivity infrastructure.

The SWD is structured as follows:

- A summary of the opinions from the stakeholders' consultations.
- An overview of market trends and forecasts in terms of applications and uptake of virtual worlds per selected EU industrial ecosystem.

[1] DECISION (EU) 2022/2481
[2] COM(2022) 28 final

- An overview on the main technological trends related to the development of virtual worlds and Web 4.0.
- A non-exhaustive mapping of various legislations that applies to virtual worlds and to the nascent development of Web 4.0.

The annexes of the SWD provide the synopsis reports of the different stakeholder's consultations, including the individual factual reports of each consultation.

Additional scientific evidence is available from a dedicated study that was carried out by the Joint Research Centre (JRC) to complement the findings of this SWD[3]. Explicit references to this work are included in the relevant sections.

[3] Hupont Torres, I., Charisi, V., De Prato, G., Pogorzelska, K., Schade, S., Kotsev, A., Sobolewski, M., Duch Brown, N., Calza, E., Dunker, C., Di Girolamo, F., Bellia, M., Hledik, J., Nai Fovino, I. and Vespe, M., Next Generation Virtual Worlds: Societal, Technological, Economic and Policy Challenges for the EU, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/51579, JRC133757.https://publications.jrc.ec.europa.eu/repository/handle/JRC133757.

## 2 CONSULTING THE STAKEHOLDERS: VIEWS ON VIRTUAL WORLDS

This section provides a summary of the main findings from the stakeholders' consultations on virtual worlds conducted by DG CNECT throughout the 1st and 2nd quarters of 2023. These findings are explained in more detail (i.e., context, stakeholders, methodology) in the synopsis report and factual reports annexed to this SWD.

The consultation exercises took as a premise the development of virtual worlds and Web 4.0 ensuring the respect of EU values and compliance with EU regulations and supporting innovation and competitiveness in Europe. The vision for openness, safety and respect is in line with the Digital Decade policy programme and the European Declaration on Digital Rights and Principles. The objective of these consultation exercises was to capture the stakeholders' views to allow DG CNECT to shape up an informed strategy, with pertinent actions, able to reflect a shared vision on how the virtual worlds should be built and developed in the future.

The consultations targeted a broad range of stakeholders according to their interest and expertise in the subject of virtual worlds and Web 4.0. These included individuals, citizens, research and academia, businesses (large-size and SMEs, microenterprises, self-companies, consulting firms), businesses associations, public authorities (Member States, regional and local public authorities, international organisations), standardisation bodies, non-governmental organisations and social partners and representatives of professions and crafts (Chambers of Commerce, Trade Unions and other profession representatives).

Given the multitude of aspects encompassed by the initiative, the large-scale consultations involved a variety of stakeholders who discussed issues covering a broad scope of sectors, as it will be shown in detail in the summary of recommendations. They encompass various dimensions of virtual worlds and Web4.0: European industry, competitiveness and autonomy; European scientific excellence, research and innovation challenges; industrial and societal applications, awareness and acceptance; impact of virtual worlds on society, ethical, legal, socio-economic issues and the expectations of citizens and end-users.

The consultation on the topic of connectivity infrastructures, a critical area for the development of virtual worlds and Web 4.0, is not part of the initiative on virtual worlds. However, connectivity infrastructure for virtual worlds is covered in a broader parallel strand by the EC's connectivity package[4] that includes the Gigabit Infrastructure Act.

### 2.1 Summary of consultations results

**Disclaimer: The views presented in this summary report (point 2.1) are not the views of the European Commission but of the stakeholders who participated in the consultations. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

The stakeholder consultations were conducted in three ways:

- European Citizens' Virtual Worlds Panel (face-to-face / online)

[4] https://digital-strategy.ec.europa.eu/en/policies/eu-rules-reduce-cost-high-speed-broadband-deployment

- Targeted Consultations (online)
- Call for Evidence (online)

The three types of consultations enabled EC services to collect a wealth of opinions shared by stakeholders coming from diverse social and professional backgrounds and geographical areas within EU and outside the EU (in the case of the call for evidence). The views of the different stakeholders were discussed and recorded during the workshops, expressed in writing through the call for evidence, or directly converted into recommendations in the case of the Citizens' Panel exercise. While focussing on the identification of opportunities and challenges of the virtual worlds, each type of consultation followed different methodologies, which meant the feedback was structured differently.

The main opinions emerging from the consultations are clustered below around two main categories: the cardinal points of the Digital Compass and the principles of the Declaration on Digital Rights and principles; and are presented in the form of recommendations from the stakeholders.

| | |
|---|---|
| Cluster 1:<br>Digital Compass cardinal points | • business<br>• infrastructure<br>• government<br>• skills |
| Cluster 2:<br>Digital Rights and Principles | • People at the centre<br>• Freedom of choice<br>• Safety and security<br>• Solidarity and inclusion<br>• Participation<br>• Sustainability |

*Table 1. Categories used for classifying stakeholder's feedback.*

### *2.1.1 Cluster 1: Digital Decade Compass cardinal points*

*Businesses*

- **Support for the uptake of new technologies**. The consultations highlighted that digital technologies are taken up at a slow pace by EU companies. For the adoption of enabling technologies, such as Digital Twins, Cloud, 5G, 6G Blockchain (NFTs), AI, AR/VR, the companies need access to finance from both the public and the private sectors. Another factor that could help with accelerating the process is **awareness raising** on the potential benefits of the virtual worlds (e.g., improvement of processes, cost saving, increase in productivity).
- **Support for research, development and deployment of technologies** underlying virtual-worlds and Web 4.0 through EU funding programs. This is especially

important in relation to industrial scenarios, which have the potential to drive significant economic growth and job creation.

- **An EU ecosystem for all players in the virtual worlds**. Collaboration among all industrial players should be encouraged, for example by creating opportunities to share knowledge and best practices. Collaboration between the industrial sector and research institutions needs to be reinforced, as well.
- **Standardisation**. The consultations pointed out that EU should takes steps in putting in place a strong industry-led standardisation system focussed on interoperability. It is necessary to provide standards and open protocols for the European players, (SMEs, research labs, entrepreneurs), and beyond internationally, in software and hardware development, 3D modelling, and digital identity. Industry stakeholders mentioned other potential standardisation needs such as developing accounting standards for valuation of virtual assets or setting up a permanent body to promote quality standards and provide advice and resources to national policy makers and organisations.
- **EU technological autonomy.** Respondents suggested to put in place measures to reduce the dependence on US and Asian hardware and to build a EU platform for virtual worlds.

*Infrastructures*

- **Digital infrastructure development.** In the citizens' viewpoint, a far-reaching infrastructural development plan should be implemented made to ensure equal and affordable access to digital technologies, through the implementation of a far-reaching infrastructural development plan. This plan should focus on affordable, financeable accessible developments for everyone. On the industry side, stakeholders underlined that the future of the industrial virtual worlds relies heavily on next-generation connectivity, including future spectrum allocation and licensing spans. They recommended that the EC assists the Member States in agreeing on common solutions for infrastructure. In the call for evidence, stakeholders stressed the necessity of fulfilling the new network capabilities and features required for virtual worlds, i.e., this meaning managing an increasing data traffic as well as evolving requirements e.g., on latency and bandwidth.

*Government*

- **Innovation-oriented policymaking.** Member States (MS) governments and EU legislators should cultivate a forward-looking attitude to integrate innovation in their policies. Innovation from industry and academia should be streamlined for having a more holistic approach, while synergies between related services, developments and related funding are fully exploited.
- **Open data**. Public bodies should make available open data to be used for the development of innovative applications for virtual worlds.
- **Regular review of existing relevant EU guidelines**. EU guidelines on ethical and technological standards should be regularly reviewed and updated to fit to the virtual worlds.

*Skills*

- **Skills for job finding in virtual worlds.** Virtual spaces entail the opening of a new economy of services and the creation of new and more inclusive opportunities, and the need for protection by the EU legislation. Young people, but also disabled persons, might be able to find jobs in different work areas and feel included. In the citizen panel and the call for evidence, stakeholders strongly voiced the idea that essential training, reskilling and upskilling, accessible to everyone wishing to work in virtual worlds, should be granted within a harmonised EU framework to allow for a certification recognised in all Member States.
- **Education and literacy.** These were recurrent topics throughout the consultations. Academia representatives pointed out that, from a teaching perspective, virtual worlds allow students and learners to better visualise complex and abstract notions, allow a higher degree of interaction and engagement, and improve memory retention. The children consulted recognised that immersive tools could enhance learning and improve learning outcomes. To be able to attain these results, it is imperative, in the citizens' opinion, that teachers and educators in the EU be aware of opportunities and risks of immersive environments and receive appropriate training to master digital tools.
- **Shortage of skilled professionals.** The lack of adequate skills in the enabling technologies may in part be responsible for the slow adoption of innovative technologies by the enterprises. Training the next generation of designers and VR experts, encouraging multidisciplinary skill sets and nurturing and supporting talent. Stakeholders representing businesses also emphasised in the workshops and the call for evidence the need to address the increasing scarcity of skilled professionals.
- **Awareness raising**. Industry representatives stressed that the general public, business leaders and other players should be aware of the multiplicity of virtual worlds (e.g., social, industrial), and understand the technology behind products presented in these environments.
- **Empowerment.** The citizens emphasised the need for EU guidelines to navigate through the virtual worlds, i.e., to understand what they are about, provide the right information on good usage and risks, etc. Moreover, indicators that can measure the social, environmental, mental and physical health impacts would be particularly useful in identifying potential threats and maintain healthy, inclusive, transparent and sustainable virtual worlds.
- **Better access to media and cultural experiences.** The virtual worlds can boost creativity and provide new ways of storytelling in diverse languages, thus reaching out to new and more inclusive audiences. EU cultural heritage, for example, becomes more accessible to young people, according to the some of the consulted stakeholders.

### *2.1.2 Cluster 2: Digital Rights and Principles:*

*People at the centre* (Technological development and regulation of virtual worlds are serving and respecting the needs, rights and expectations of users)

- **Participatory design.** Users get involved in the creation of tools and applications for virtual worlds so that their needs should be better met.
- **Health concerns** potentially deriving from the use of virtual worlds, especially for young people should be measured and addressed by the EC, as shown by the results of the citizen panel and call for evidence consultations.

*Freedom of choice* (The use of virtual worlds is a free choice for individuals – without disadvantages for those who are not participating)

- **Digital identity in the virtual worlds.** The citizens expressed the view that anonymity rights and authentication obligations should be regulated at EU level. This would give a sense of security. Industry representatives argued that, based on healthy commercial values and a well-designed digital identity system, companies and users could collaborate better. Fakes and fraud might also be avoided.

*Safety and security* (European citizens need to be kept safe and secure, including the protection of data and preventing manipulation and theft)

- **Personal data.** Companies should be transparent about the usage and guarantee the protection of personal data.
- **Company and user certification for the virtual worlds.** The citizens have proposed the issuing of common standards-based certificates for the different usages of the virtual worlds.
- **Protection of children and young people** should be taken into account, as pointed out by respondents in the call for evidence.
- **Mitigation of risks** of disinformation, manipulation, cyberbullying and hate speech in virtual worlds.

*Solidarity and inclusion* (Society members share fairly benefits and obligations; Equal accessibility for all citizens is granted – regardless of age, income, skills, technological availability, country, etc.).

- **Sharing knowledge.** Particularly relevant for industries, stakeholders stressed the importance of sharing guidelines and best practices based on an EU common vision on virtual worlds (e.g. in an open-source library). Moreover, it could be useful to share results from EU and national funded projects. Industry stakeholders also expressed the wish to have a platform that serves as a marketplace for ongoing initiatives and new technologies relevant for virtual worlds.
- **Partnerships and collaborations**. Apart from networking and shared projects, collaboration in initiatives such as local pilot projects (e.g. group of people with specific needs) or living labs in different areas may have a real impact.
- **Inclusion**. Citizens put forward the recommendation for legislation in favour of work-life balance, and of citizen inclusion (i.e., disabled persons, digital illiterate people). Also, the respondents in the call for evidence urged the EC to develop comprehensive and inclusive policies for the development of virtual worlds. Some

respondents suggested the revision of the European Accessibility Act (as it does not directly target virtual worlds technologies) to ensure virtual worlds are accessible and inclusive for people with disabilities from the outset.

*Participation* (The users are actively and equally involved in the design, running and development of virtual worlds).

- **Close collaboration between players in the regulatory and standard-setting processes, under EC lead.** Researchers, industry, legislators, social partners, officials, as well as users should join participatory forums and platforms to work together to develop and regulate virtual worlds. This would ensure the fairness and transparency of the processes.

*Sustainability* (The set-up and use of virtual worlds is environmental-friendly).

- **UN's Sustainable Development Goals (SDGs).** Virtual worlds should be built with the 17 SDGs[5] embedded in them.
- **Environmentally friendlinessvand sustainability.** Companies building virtual worlds should make sure that energy efficiency requirements are complied with. The impact on environment should be always measured (e.g. following the increase in server capacity). The citizens proposed that, at EU level, instruments should be put in place to have the equipment related to virtual worlds included in the circular economy. In addition, citizens and industries should be made aware of the overall environmental footprint of the use of virtual worlds.

The following sections will present issues identified by the consultations, market trends and sector opportunities, as well as technological trends and regulatory issues.

[5] https://sdgs.un.org/goals

# 3 MARKET TRENDS AND SECTOR OPPORTUNITIES FOR VIRTUAL WORLDS

## 3.1 Global market trends

There are numerous forecasts on the growth of virtual worlds, such as metaverses, and enabling technologies such as Extended Reality (XR), Augmented Reality (AR) and Virtual Reality (VR), and their potential impact on various industries.

Virtual worlds, blending the physical with the virtual in real-time, have the power to revolutionise people's daily social- and work life and to open a wide range of opportunities in many sectors including education, health, manufacturing, culture, communication, and many others.

At present, there is a limited number of robust studies in the field of virtual worlds, however, existing research and figures, as well as real-life applications indicate a favourable context for the future expansion and uptake of these evolving technologies.

The global market for virtual worlds is expected to grow from EUR 36.26 billion in 2021 to EUR 918.23 billion by 2030[6]. At the same time, the virtual worlds' economy could grow up to around EUR 12 trillion by 2030[7].

Moreover, according to Bloomberg data, the global metaverse market size is expected to grow from EUR 27 billion in 2022 to over EUR 800 billion by 2030[8]. This growth will contribute between 10 and 12.8 percent to the wider development of the digital economy's share in the overall GDP, as per International Monetary Fund[9] estimates.

As a major technology enabler for virtual worlds, the global VR/AR industry has also matured over the past years. Market forecasts predict that the industry has the potential to grow up to EUR 766 billion by 2025[10], and to contribute around EUR 1.3 trillion to the global economy by 2030[11]. In terms of employment, it is predicted that over 23 million jobs will be impacted globally by the adoption of XR technologies by 2030[12].

[6] The Brainy Insights, according to market research firm International Data Corporation.
[7] Ecorys (2022). VR/AR Industrial Coalition: Final report; Deloitte (2022). A whole new world? Exploring the metaverse and what it could mean for you
[8] Bloomberg with data from Verified Market Research
[9] IMF, Citi Global Insights
[10] Market Research Future (2021), ARVR Market research report – Global forecast till 2027
[11] PwC (2019), Seeing is believing,
[12] ibid

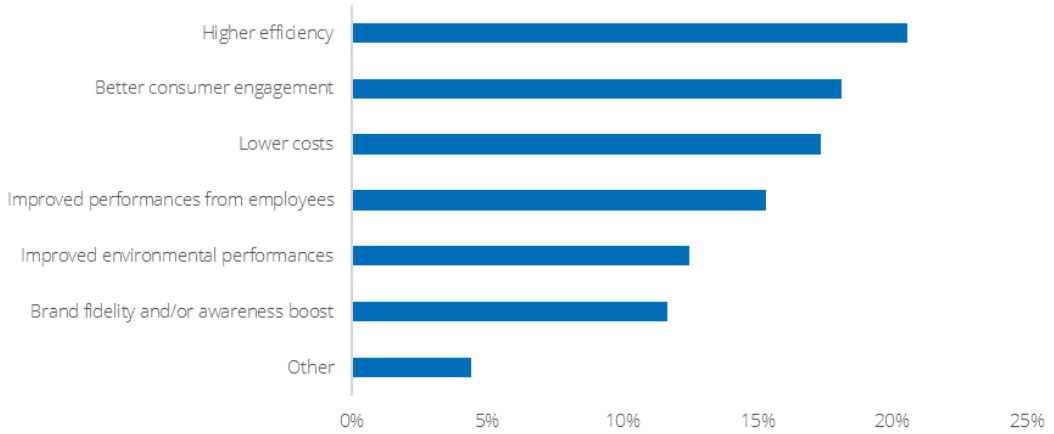


*Figure 1.Identified gains brought by VR/AR solutions. Source: Survey: ECORYS VR/AR Industrial Coalition - Strategic paper*

Virtual worlds are becoming popular globally. A study conducted in 2022 on 3,400 consumers by global management consulting firm McKinsey & Company[13], revealed that almost 60% of consumers using today's versions of virtual worlds have a positive view of transferring everyday activities into virtual worlds. Respondents were particularly positive with regards to the connectivity and communication opportunities being enabled in emerging virtual worlds, and the results show high potential for activities including shopping, social networking, and education in this virtual space. Further estimates predict that, by 2026, 25% of people will spend at least one hour per day in virtual worlds for work, shopping, education, social activities, or entertainment purposes, among others[14].

In a recent survey, 95% of business leaders expect virtual worlds to have a positive impact on their industry within five to ten years[15]. Business leaders participating in the survey were C-level executives from 448 companies across Europe, Asia, and the United States, with basic understanding of at least two virtual worlds technologies and applications. This is also reflected in funding, as large technology companies, venture capital and private equity have already invested more than EUR 120 billion in virtual worlds in the first five months of 2022 worldwide, more than double compared to the EUR 57 billion invested throughout the whole of 2021[16].

While major developments are occurring globally, most innovation activities are concentrated in the US, South Korea, and China[17].

On a global scale, US tech companies are key enablers and leaders of the technological developments for virtual worlds. In addition to Meta, several other US-based companies including Apple, Microsoft, Nvidia, Unity, Roblox, Snap[18] and Epic Games[19], are working

[13] McKinsey & Company (2022). Value creation in the Metaverse: The real business of the virtual world
[14] Gartner Predicts 25% of People Will Spend At Least One Hour Per Day in the Metaverse by 2026
[15] McKinsey & Company (2022). Value creation in the Metaverse: The real business of the virtual world
[16] ibid
[17] VR/AR Coalition - Strategic Paper https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1
[18] Nextrope (2022). Building an Open World: The State of the Metaverse: The next step in an ever digitalized ecosystem
[19] https://www.theverge.com/2023/3/22/23645702/epic-games-state-of-unreal-2023-keynote-biggest-announcements-fortnite-engine

on creating the infrastructure that is expected to serve as the basis for emerging virtual worlds.

In China, leading participants in the virtual worlds market include the Alibaba Group, Baidu, Tencent Holdings and NetEase. As part of their plan to boost China's computing power, China's big three mobile operators - China Telecom, China Mobile and China Unicom - formed the metaverse industry committee which aims to strengthening innovation and integration among virtual worlds builders. Moreover, in late 2021 major tech companies such as Alibaba, Baidu, NetEase and Bytedance announced plans to either launch their own virtual worlds projects or invest in virtual worlds companies[20].

In February 2022, the Korean Ministry of Science and ICT announced an investment of at least EUR 186.7 million to create its virtual worlds ecosystem. The investment was part of the Digital New Deal, a set of policies to develop key digital technologies to overcome the economic crisis. The government also created a metaverse industrial alliance to coordinate and facilitate the development of XR platforms. It is currently composed of 17 companies, including major wireless carrier SK Telecom, auto giant Hyundai and 8 industry groups, such as the Korea Mobile Internet Business Association[21].

Contrary to these countries, in the EU there are no tech-giants to lead the investment in the development of virtual worlds over the next decade. However, the EU is strong in research and innovation for middleware and software. EU countries also have a competitive advantage in terms of content, owing to their large cultural and language diversity.

Research, and development (R&D) in XR is particularly broad in Europe, accounting for around one-third of the global market[22]. It has matured significantly over the past few years, and it is expected to grow from EUR 7.95 billion in 2021 to EUR 88.87 billion by 2030[23]. Similarly, the European (including non-EU countries) VR/AR industry is significant in size, being estimated at EUR 9.6 billion in 2021, while the EU VR/AR market size was estimated at EUR 7.1 billion in the same year, a 26% growth rate from the previous year[24]. The market is expected to grow at a similar pace over the next years, estimating a 37% compound annual growth rate between 2021 and 2026[25].

The total market value of the European VR/AR industry is expected to increase to between EUR 35-65 billion by 2025, representing a gross added value of between EUR 20-40 billion. Wider supply chain impacts are also expected to indirectly increase production value to between EUR 35-70 billion[26].

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[20] China's Metaverse Industry Committee admits 17 new firms | Reuters; China's telcos join race for computing supremacy | Light Reading

[21] South Korea to invest $187M in national metaverse project (cointelegraph.com); Korea launches 'metaverse' alliance - The Korea Times

[22] The global market value was averaged, based on multiple market research companies (BusinessWire Global XR Forecast, Mordor Intelligence Global XR Forecast, Research and Markets Global XR Forecast, VR/AR market size 2024 | Statista)

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

[24] Ecorys (2022). VR/AR Industrial Coalition

[25] ibid

[26] Ecorys (2021). XR and its potential for Europe

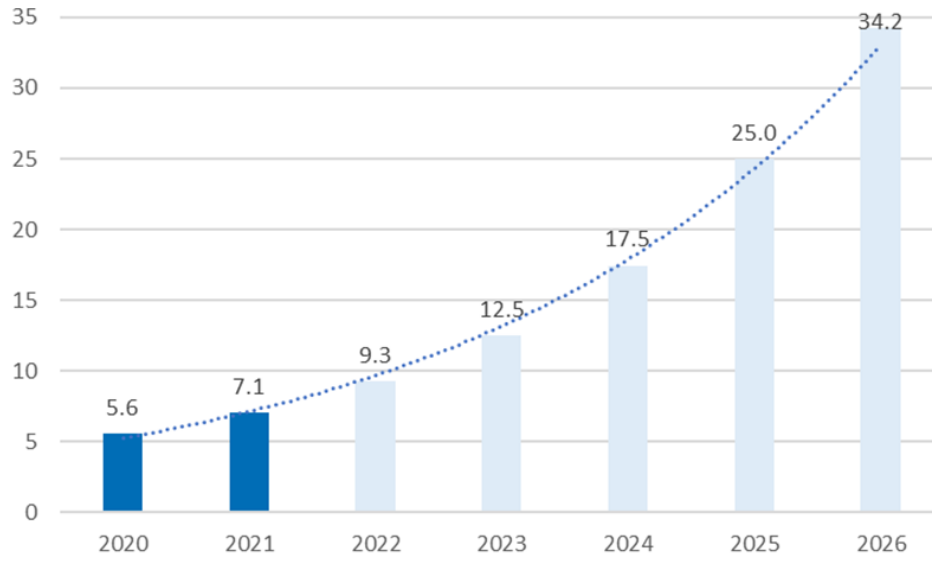


*Figure 2 European VR/AR market size – billion EUR (2020−2026) Source: Survey: ECORYS VR/AR Industrial Coalition - Strategic paper*[27]

The impact on employment is expected to be highly significant, as estimates indicate that the XR market growth in Europe (including non-EU countries) is expected to directly create new employment in the technology sector for up to 860 000 people, and that 1.2 to 2.4 million new jobs will be directly or indirectly (across other industrial sectors) created by 2025[28]. Globally, it is estimated that more than 23 million jobs will be enhanced by XR adoption by 2030[29]

European XR market activities range from the development of hardware components (i.e., sensors) to advanced manufacturing techniques that include AI and machine learning. Developments are present in all industrial sectors, from healthcare to manufacturing and education[30].

The largest shares in the VR/AR European market are represented by the gaming, media, and entertainment sectors. In terms of market size per sector, these sectors account for almost half of the market while retail represents 15%, followed by healthcare (11%), military and defence (7%) and manufacturing (7%). Revenue in the gaming industry tops the income league, representing around 29% of the total VR/AR revenues[31].

[27] VR/AR Coalition - Strategic Paper https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1
[28] Ecorys (2021). XR and its potential for Europe
[29] ibid
[30] ibid
[31] Ecorys (2021). XR and its potential for Europe; Ecorys (2022). VR/AR Industrial Coalition

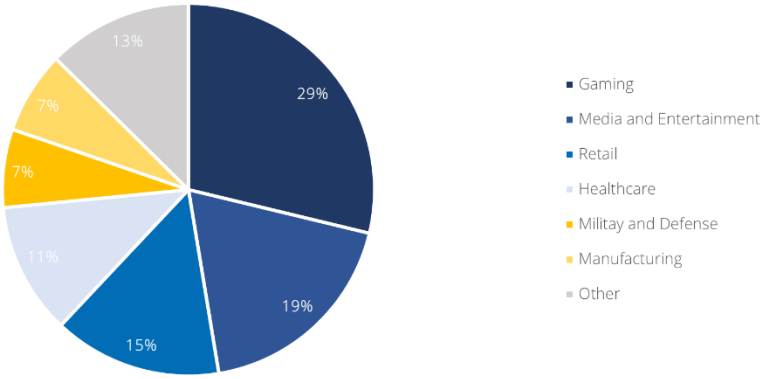


*Figure 3 European VR/AR market size per sector, 2021 (% of total). Source: Survey: ECORYS VR/AR Industrial Coalition - Strategic paper*[32]

Germany is among the strongest EU countries for XR development, with Berlin as the biggest hub, and growing ecosystems in Hamburg, Munich, Cologne, Stuttgart and Darmstadt. Alongside Germany, some of the forerunners in developing the European XR market are France, with most prominent hubs in Paris and Laval, the Netherlands, the Nordic countries, Spain and Italy. Germany's XR ecosystem is mostly focused on entertainment and media. Similarly, in the Nordic countries, Helsinki, Stockholm, and Copenhagen have a well-established ecosystem for XR applications related to entertainment and gaming, as well as cinematic industries. Helsinki is also an important European hub for VR headsets manufacturing. Helsinki-based company Varjo is considered amongst the most advanced XR companies in the world producing high-quality VR headsets[33].

While developments in XR technology are on the rise and the EU shows high potential and has a strong presence particularly in the gaming, media, and entertainment sectors, there is much room for development in the wider application of emerging virtual worlds to keep up with the major players in the field.

## 3.2 Hurdles faced by Web 4.0 SMEs and start-ups in the single market

SMEs and start-ups are essential pillars in the development of the EU's economy, as they play a very important role in the digital and green transition, as well as in the achievement of sustainable growth.

The transition to Web 4.0 will be facilitated by a diversity of stakeholders, including large tech companies, academia, research organisations, as well as start-ups and SMEs. This next technological transition intensifies the need for stakeholders to cover the development of key technologies, from hardware to applications, such as extended reality (XR), artificial intelligence (AI), IoT or blockchain.

[32] VR/AR Coalition - Strategic Paper https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1
[33] ibid

Technologies combining the virtual and physical world might unleash changes of system operation or product experience on a scale and pace never seen before. Innovation in this field is expected to be largely driven by high-tech start-ups and SMEs able to develop agile solutions that may accelerate market transition and business ecosystems. SMEs are drivers for innovative technology solutions which allow the industry to adapt to new market realities and, at the same time, deliver gains in productivity and sustainability.

At present, there are over 130 start-ups in the EU working on generative AI.[34] Similarly, most companies developing XR technologies in Europe are start-ups and SMEs. According to a Ecorys[35], 31% of companies in the XR sector in Europe have below 5 employees, 30% between 6-10, and 25% up to 50 employees, while companies with over 250 staff members represent only 10% of the European XR ecosystem.

Despite growing AI and XR ecosystems, start-ups and SMEs face multiple challenges in achieving their potential when it comes to innovation and uptake of technologies facilitating the transition towards Web 4.0. Albeit clear benefits for using emerging virtual worlds solutions like cost reduction, process optimisation, scalability, productivity improvement, sustainability, and quicker time-to-market, such technologies could be easy to dismiss as too advanced for most small businesses to capitalise on. Some of the main reasons are linked to the fragmentation of the EU's Web 4.0 industrial ecosystem, challenges in accessing funding, gatekeeping by large tech players, difficulties to win customers and commercialise technology solutions as well as challenges in attracting skilled employees.

Figure 4 below highlights the most pressing barriers related to resources, identified by start-ups and researchers for the XR ecosystem.

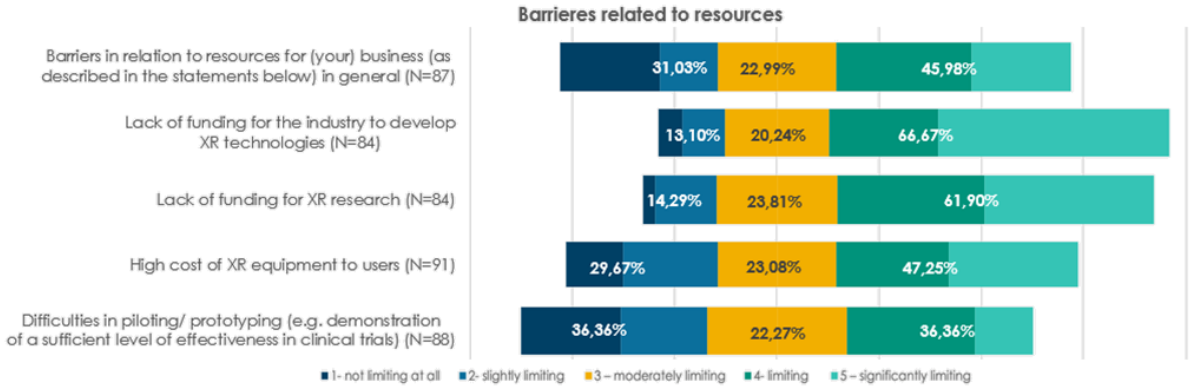


*Figure 4. Barriers related to resources in XR Source: Visionary Analytics, 2022. XR company representatives and XR researchers/academics survey conducted between 16 November 2021 and 24 January 2022.*

**Access to funding opportunities** is a key challenge, as public and private funding at EU's and national level is often deemed insufficient and not tailored to the specific needs of SMEs and start-ups.

In the AI start-up sector, capital invested in 2017 was about EUR 220 per capita, whereas in Europe per capita investment was as low as EUR 3 in Italy, EUR 58 in Finland, and

[34] Sifted (2023) Europe's generative AI startups, mapped. https://sifted.eu/articles/europe-generative-ai-startups
[35] Ecorys (2021). XR and its potential for Europe

EUR 123—the highest share in Europe—in Sweden. Europe had only 10 percent of the world's 185 "unicorns"—private start-ups with a value of at least EUR 1 billion—compared with 54 percent in the United States[36].

The trends in investments have not changed significantly over the past years. According to a report by the German AI start-up association, EU start-ups received EUR 6 investment per capita, while US and Israeli start-ups received a EUR 71 and EUR 133 investment per capita in 2020[37].

When accessing public funding, SMEs and start-ups are often faced with complex application processes that bring excessive administrative burdens. A 2022 Ecorys survey on XR technologies identified the abundance of red tape as one of the biggest issues for respondents, who consider that the application process is not suitable for small companies but rather adapted to the needs of companies with large in-house scientific laboratories for XR[38]. The same study reveals that there is a general lack of communication and awareness of funding possibilities among SMEs and start-ups, and a lack of European venture capital. SMEs and start-ups struggle to find the right investor and report difficulties to access European venture capitals due to various factors, including the risk aversion/low-risk acceptance, the underdeveloped venture capital culture and availability in Europe, and the lack of long-term vision/understanding of what VR/AR technologies can do or need to evolve from the point that the project is presented. Due to these, many start-ups in the EU are interested in scaling-up their business are led to look for venture capitals, angel investors or seed funding outside of the EU, particularly in the US and in North America. This can undermine the EU's efforts to strengthen its own innovation capacity and increase its dependence on external sources of technology and capital[39].

While there are many SMEs and start-ups that are developing innovative and creative technology, the global market is dominated by a small number of large companies accountable for most developments. It is quite common practice that SMEs and start-ups in the EU are acquired by non-EU bigger players, formally removing EU companies from the overall ecosystem. This phenomenon prevents companies from growing and scaling-up in the EU and further exacerbates the challenges linked to accessing funding.

Web 4.0 SMEs and start-ups in the EU are also faced with a **fragmented ecosystem,** which leads to challenges in establishing collaborations, sharing knowledge and best practices within the sector. The lack of awareness and visibility of actors along the value chains is a major issue for cooperation. This hinders innovation and leads to other difficulties such as finding the right partner to set up consortia for calls, an issue particularly relevant for securing EU funding. Addressing these issues would build stronger collaborations across hubs and borders.

**Winning customers and commercialising technology solutions** is yet another challenge for SMEs and start-ups in the EU working in virtual worlds or Web 4.0 technologies. In the AI sector, established companies have so far proved themselves reticent in becoming

[36] McKinsey & Company (2019). Notes from the AI frontier tackling Europe's gap in digital and AI
[37] https://ki-verband.de/wp-content/uploads/2021/12/dl-studie-startups-ki.pdf
[38] Ecorys (2022). VR/AR Industrial Coalition
[39] ibid

customers of AI start-ups. A study by the German technology trade association Bitkom reported in 2019 that 66% of the surveyed companies are not using AI-based technologies because of the high investment costs[40]. Similarly, in the XR sector, private investors in the EU are reluctant to fund XR solutions, particularly hardware[41].

**Skilled labour shortage** is a general challenge in the technology sector. There is a pressing need for specialists in technologies such as XR, core technologies of virtual worlds that could grow further if left unaddressed[42]. Companies struggle to find ICT specialists with advanced digital skills in Europe.[43] This challenge is particularly affecting Web 4.0 start-ups and SMEs in the EU. Many AI start-ups cite the red tape linked to hiring and retaining talent as a major obstacle for growth.[44]

### 3.3 State of play and opportunities for the private and public sectors

Virtual worlds open a range of opportunities in many industrial sectors such as manufacturing, retail and customer service, tourism, entertainment, media, and societal areas such as health and education.

While potential impact of new virtual worlds is expected to hold significant implications for all business, B2B and B2C (with different goals, challenges and opportunities) and public sectors, the extent of the impact will vary for each area of activity. Some sectors are already experiencing impact from the use of virtual worlds (in particular, industrial digital twins, tourism, entertainment, training of surgeons) but all sectors are likely to experience significant changes in the next decade of the way they work, including the consumer and retail, cultural and creative industries, media, education, and healthcare sectors.

The potential economic value generated by virtual worlds is estimated to reach EUR 2-2.6 trillion for e-commerce by 2030, advertising is expected to show an impact of EUR 144-206 billion, and the impact on the gaming market is estimated at EUR 108-125 billion. Similarly, the impact on education is predicted to be of EUR 180-270 billion for the academic virtual learning market[45].

[40] https://ki-verband.de/wp-content/uploads/2022/03/Startup-Strategie_Stellungnahme-KI-Bundesverband.pdf
[41] Visionary Analytics (2022). Extended reality: opportunities, success stories and challenges (health, education) – Final Report
[42] VR/AR Industrial Coalition – Strategic paper, Publications Office of the European Union, 2022
[43] https://ec.europa.eu/eurostat/databrowser/view/ISOC_SKE_ITRCRN2__custom_6527549/
[44] https://ki-verband.de/wp-content/uploads/2022/03/Startup-Strategie_Stellungnahme-KI-Bundesverband.pdf
[45] McKinsey & Company (2022). Value creation in the Metaverse: The real business of the virtual world

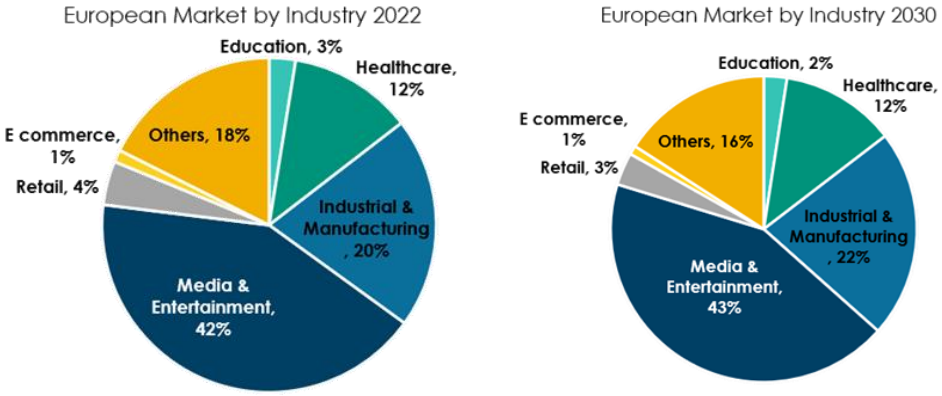


*Figure 5. European XR market by industry. Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[46]

The following section explores in more detail potential use cases, with real-life application examples, and benefits in several industrial ecosystems[47].

### *3.3.1 Cultural and creative industries*

There is immense potential for the uptake of XR technologies and virtual worlds within the creative and cultural industries from gaming industry to fashion and design. Existing applications are demonstrating the added value of such technologies in the consumption experience of existing cultural content as well as in the creation of new content, the consumer experience of fashion products (i.e. customisation), as well as the potential for cross-sectoral spill-overs and innovation in creative industries (e.g. cross-overs between gaming platforms and fashion and live events).

The EU has an extraordinarily rich cultural landscape, which includes a diversity of natural, built, and archaeological sites, museums, monuments, artworks, historic cities, and literary, musical, and audio-visual works, together with the knowledge, practices, and traditions of people in Europe. This richness represents an important enabler for the cultural and creative industries ecosystem, one of the 14 industrial ecosystems identified as key for Europe's single market and the green and digital transition[48].

The broader EU policy framework for the ecosystem includes the EU Industrial Strategy[49], which sets out key industrial policy objectives for supporting growth and competitiveness, a fair and resilient recovery and to deliver on the ambitions of the twin transition. The cultural ecosystem employed 7.7 million people in 2022, equivalent to 3.8% of the total

[46] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education

[47] For an elaboration on the opportunities across different sectors see Hupont Torres, I., Charisi, V., De Prato, G., Pogorzelska, K., Schade, S., Kotsev, A., Sobolewski, M., Duch Brown, N., Calza, E., Dunker, C., Di Girolamo, F., Bellia, M., Hledik, J., Nai Fovino, I. and Vespe, M., *Next Generation Virtual Worlds: Societal, Technological, Economic and Policy Challenges for the EU*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/51579, JRC133757.https://publications.jrc.ec.europa.eu/repository/handle/JRC133757.

[48] Commission Staff Working Document, Annual Single Market Report 2021, SWD/2021/351 final https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

[49] Communication from the Commission, Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, COM/2021/350 final, 5 May 2021 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en

employment in the EU and representing 1.2 million enterprises[50]. Furthermore, the European media sector contributes to job creation and growth with a turnover exceeding 3% of GDP[51]. Key characteristics of the ecosystem include its diversity[52], and that it is made up of over 99% SMEs. Considering this, the deployment of such technologies in the EU cultural and creative landscape could bring many opportunities for its future development, contributing to innovation, growth and competitiveness.

However, the ecosystem faces key challenges, which include fragmentation, the small size of most companies, high self-employment, lack of skills, underinvestment, and lack of IPR literacy. In this context, it will be important to ensure that CCIs in the EU are well-equipped to take full advantages of the opportunities offered by XR technologies and virtual worlds.

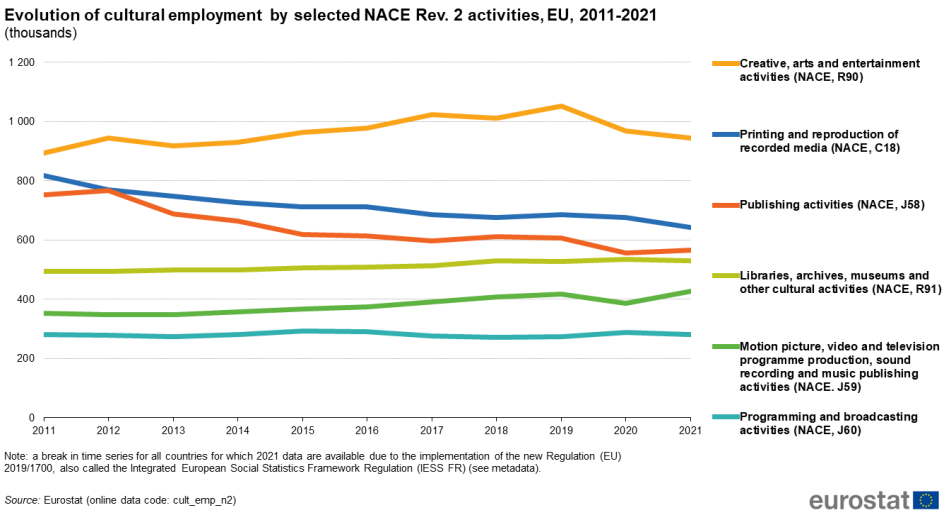


*Figure 6. Evolution of cultural employment by sector*

Several real-life applications of such technologies already exist across different strands of the creative and cultural industries, including gaming, music and live performance, fashion and the art market, among others.

At both global and European level, the gaming industry has been a forerunner in the use of XR technologies. There are numerous examples of 3D interactive worlds, where players can interact in real-time, accessed through a 2D screen. Many "metaverse-like" games are widely popular and profitable, such as the virtual world-building game Minecraft. Originally developed by the Swedish video games company Mojang, it was acquired by Microsoft for EUR 2.5 billion 2014 [53]. By 2021, Minecraft had sold 240 million copies, making it one of the most popular games of all time [54].

[50] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Culture_statistics_-_cultural_employment
[51] COM(2020) 784 final
[52] The ecosystem includes sectors such as: architecture, archives, libraries and museums, artistic crafts, audiovisual (including film, television, video games and multimedia), tangible and intangible cultural heritage, design (including fashion design), festivals, music, literature, performing arts, (including theatre and dance), books and publishing, radio, and visual arts).
[53] TecCrunch (2014) *"Microsoft Has Acquired Minecraft For $2.5 Billion"* https://techcrunch.com/2014/09/15/microsoft-has-acquired-minecraft/
[54] Microsoft (2021),

In Central Europe, Superhot VR[55], a video game developed in Lodz, Poland, became one of the few video games developed for VR to receive critical acclaim and widespread public success. The game was originally launched in 2016, but it was improved and adapted in terms of VR interaction and released again in 2019. Another success story is Beat Saber, a VR game developed by Czech company Beat Games and released in 2019. Beat Saber became one of the most popular VR games ever, selling over 1 million copies in less than nine months. From its release to October 2022, the game made EUR 255 million in revenue[56]. Following this success, Beat Games, was acquired by Facebook's Oculus division.[57].

Media and entertainment industries are also seeing a steady increase in the application of XR technology solutions. In the media sector, several organisations, audio-visual production houses and facility service providers are using virtual studio infrastructure. While the concept of virtual production itself is not new, developments in XR technology are making it possible to merge 2D and 3D environments in a seamless way[58]. Such developments show high potential for virtual production to expand further. Standing at EUR 1.6 billion in 2022, the market for virtual production tools is expected to reach EUR 2 billion in 2023[59]. In the live events sector, one particularly famous example of virtual-worlds application is Travis Scott's livestreamed online concert held on gaming platform Fortnite in April 2020, which gathered an audience of 12 million participants[60].

From the European music field, one relevant example is the French Metaverse music platform *Stage11*[61], that aims to create an immersive music experience by combining gaming, mixed reality, and digital collectibles together. Another European initiative, *culture vr*[62], is a directory of French works and VR creations, comprising a professional network. The aim is to make information and knowledge on French VR artistic content more accessible, and to help content creators obtain the contacts necessary to conduct their business. Launched in 2017, it now references 150 works alongside the professionals in the field involved.

Virtual worlds applications are also present in the fashion industry, allowing for an enhanced consumer experience as well as new models in which fashion is created and enjoyed by consumers. In March 2022, the first *Metaverse Fashion Week* event took place on Decentraland, one of the most popular virtual worlds to date. The second edition was hosted in March 2023, with established brands such as Adidas, Tommy Hilfiger and Hugo Boss showcasing their digital wearables collections[63].

In 2021, the Italian luxury brand Gucci has also launched its own collection of virtual sports shoes. After purchasing the shoes, consumers can use them in the Gucci app and the

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[55] Ecorys (2021). XR and its potential for Europe
[56] Rodriguez, Bobrowsky and Horwitz, *TikTok Parent ByteDance Battles Meta for Virtual-Reality App Developers*, in Wall Street Journal, 13 April 2023.
[57] Ecorys (2021). XR and its potential for Europe
[58] NEM (2022). NEM contribution to the XR coalition
[59] Deloitte, Virtual production gets real: Bringing real-time visual effects onto the set, 2022
[60] Fortnite's Travis Scott virtual concert watched by millions - BBC News
[61] Stage11 - Reimagining Music for the Metaverse
[62] Ecorys (2021). XR and its potential for Europe
[63] Metaverse Fashion Week 2023 (mvfw.org); How Retail Got Real At Metaverse Fashion Week With AI, AR, Interoperability And Phygital Components (forbes.com)

VR social platform VR CHAT or try them out on the game platform Roblox[64]. The *H&M Innovation Metaverse Design Story*[65] collection is a more recent example on the interaction between virtual and analogue fashion in virtual worlds. It includes both physical garments and virtual pieces to wear digitally. The collection is dedicated to promoting more sustainable materials, technologies and production processes.

Virtual worlds also present a great potential to improve access to and engagement with European cultural heritage, as illustrated by AR/VR use cases such as 'ARA as it was', creating an AR/VR experience of the Ara Pacis in Italy[66] or the virtual reality experience based on a work by R.W. Ekman at The National Museum of Finland produced by Finnish company ZOAN[67]. . Also, art galleries are displaying artworks in virtual worlds, as it happened in 2021 with Sotheby's opening of a gallery in Decentraland.

The VR/AR Industrial Coalition strategic paper includes many other examples in the field of cultural heritage, music, publishing, visual and performing arts, etc. It recognises that cultural activities can, in fact, be an effective first point of contact with VR/AR technologies and can spread knowledge, social acceptance and awareness of their potential.

### *3.3.2 Tourism*

XR applications in the tourism sector already exist, enhancing tourists' experiences in many ways. Some use cases of XR technology are reflected in AR solutions providing real-time information on traffic and hotels, or displaying contextual insights based on the user's location, as well as VR solutions such as virtual tours. The benefits are vast, ranging from facilitating travel arrangements for tourists, providing efficient business solutions for the tourism industry, improving the sustainability and inclusiveness of tourism, to benefitting the preservation of cultural and natural heritage. The potential to recreate a real-world location in a photorealistic way could also bring entirely new business models in leisure and cultural tourism[68]. In 2020, almost one in ten enterprises in the EU's non-financial business economy belonged to the tourism industries sector employing 10.9 million people.

[64] Ning et al. (2021). A Survey on Metaverse: the State-of-the-art, Technologies, Applications, and Challenges
[65] A metaverse design story | H&M US (hm.com)
[66] The Ara as it was | Museo dell'Ara Pacis
[67] VR/AR Industrial Coalition – Strategic paper, Publications Office of the European Union, 2022
[68] Ecorys (2021). XR and its potential for Europe

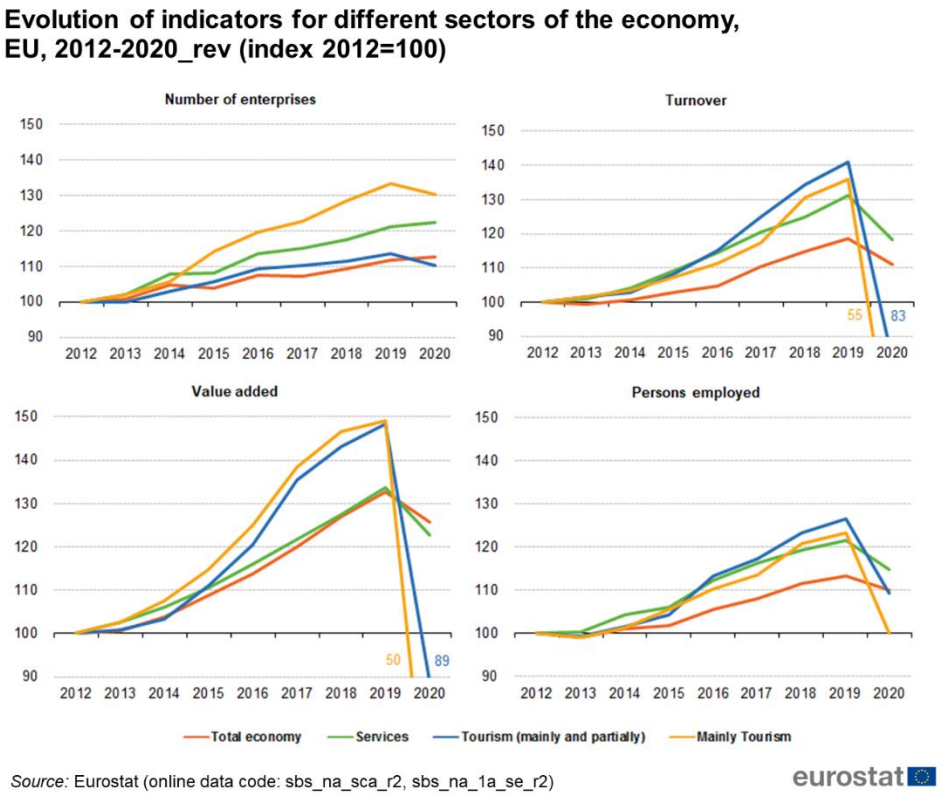


*Figure 7. Evolution of indicators for different sectors of the economy, EU 2012-2020 (Tourism)*

In Europe, initiatives offering VR tours to promote the cultural and natural European heritage are increasing. Virtual tours are being used to allow users to visit cities and natural landscapes, either through 360° video technologies or VR headsets, entirely in a virtual space. This model has been particularly beneficial both for tourists and destinations during the COVID-19 pandemic, as it made it possible for touristic activities to carry on despite the mobility restrictions applicable at the time. Onsite tourism can also be facilitated through such applications, by offering real-time contextual information as well as an enhanced experience of touristic spots.

There are many examples, including a project developed at the University of Athens bringing tourists on a virtual tour of the Greek capital, and many other tourist companies offering enhanced experiences of the city's Acropolis. Most other countries in Europe offer similar services. Some further examples include 3D virtual tours of the Albanian capital Tirana, Dracula's castle in Romania and the Palace of Versailles in France among many others[69]. In Croatia, a project funded by the Split-Dalmatia Country Tourist Board recreated a virtual version of the Diocletian Palace. Furthermore, as part of the UnderwaterMuse project funded by the European Regional Development Fund, the Museum of Kastela allows the visitors to virtually visit an underwater archaeological site of Siculi[70].

[69] Ibid.
[70] About the Project - UnderwaterMuse - Italia-Croatia (italy-croatia.eu)

### *3.3.3 Manufacturing*

Industrial virtual worlds - a sector that uses virtual twins to mirror and simulate real machines, factories, cities, transportation networks, and other complex systems including entire value chains[71] - is set to have a major impact on the manufacturing industry as digital advancements in this sense are making real-time, fully immersive, and synchronous simulations of the real world possible.

The industrial virtual worlds are expected to drastically change manufacturing processes by unlocking significant new value for businesses and societies. Some of the benefits include facilitating the production of customised products, decreasing errors, and solving real-world problems in product development digitally. Moreover, by allowing businesses to model, prototype, and test large numbers of design iterations in real time and in an immersive, physics-based environment before committing physical and human resources to a project, industrial virtual worlds tools could bring major contributions to decreasing the waste of materials engaged in production[72]. The number of use cases of such technologies is vast, stemming across all product manufacturing sectors including simulated machines, factories, transport, networks, and other complex systems.

The industrial virtual worlds can simplify radically the interaction between humans and machines in the factory environment, making factory jobs accessible to a larger number of people, and thus minimising the talent shortage currently experienced in the manufacturing industry.

At the core of the industrial virtual worlds will be the digital twin—a virtual model designed to accurately reflect a real-world object. The digital twins' market is expected to rise substantially by 2030, up to EUR 67 billion and EUR 117 billion, according to two estimates conducted by research companies Markets and Markets and Allied Market Research respectively[73].

### *3.3.4 Automotive*

There are multiple use cases for virtual worlds in the automotive industry, from product and process engineering to sales and marketing. Some examples include product design and assembly, staff training, virtual test drive and virtual showrooms, virtual repair-guides or simulations of upgrades and accessories[74].

As a component of the manufacturing ecosystem, the automotive industry is also set to be heavily impacted by the uptake of digital twins and companies are already experimenting with real-life applications in product design. For instance, BMW is experimenting with creating digital twins of entire factories and designing products using Nvidia's Omniverse technology[75].

[71] MIT Technology Reviews Insight (2023) The emergent industrial metaverse
[72] ibid
[73] ibid
[74] BCG (2022). The Corporate Hitchhiker's Guide to the Metaverse
[75] McKinsey & Company (2022). Value creation in the Metaverse: The real business of the virtual world

A more recent breakthrough for virtual worlds in the European automotive market is Renault Group's 2022 launch of its own industrial metaverse[76]. Some of the use cases cited by the company include the feed of all industrial data into a virtual world, allowing for corrections and improvements in the production processes in real time, and a global supervision tool that gives real time alerts to risks or anomalies in all transport operations while also proposing crisis management scenarios. By 2025, Renault estimates that its metaverse will generate savings of EUR 320 million, plus EUR 260 million in inventory savings, a 60% reduction in vehicle delivery time, a 50% reduction in the carbon footprint of vehicle manufacturing and a contribution to the 60% reduction in warranty costs targeted by the Group.

Beyond product manufacturing, the automotive industry has also explored the applications of virtual worlds to enhance customer experience, as well as the work environment and training for employees. FIAT is reinventing its interaction with customers through the FIAT Metaverse Store[77] launched in Italy with its flagship model: the New 500 La Prima by Bocelli. Inside the FIAT Metaverse Store, customers can discover, configure, and even complete the purchase experiences, recreating the feel of a showroom from the comfort of their homes. It is the world's first metaverse-powered interactive showroom, which makes the brand a frontrunner in offering an immersive and simple brand experience. Moreover, Volkswagen uses VR to power their own portal, through which staff can access VR meeting rooms, training simulations, and learning material archives[78].

### *3.3.5 Telecommunications*

Communication service providers (CSPs) are key enablers for the development and future uptake of XR technology solutions as providers of 5G and soon 6G connectivity infrastructure, which is an essential resource in a digitally connected world[79].

Moreover, their access to customers and market presence as consumer trusted entities is set to give them a competitive advantage to developing novel virtual-worlds solutions, as well as bringing XR technologies into their own internal learning experience and operating models[80].

Beyond infrastructure, telecommunication companies have started investing into developing their own virtual worlds. Some examples include Deutsche Telekom, Orange, and Vodafone.

Deutsche Telekom was the first telecommunications company to create its own metaverse experience on Roblox. *Beatland* was launched in 2022 as a virtual club experience. Apart from experiencing a virtual nightlife, users can get actively involved in role-playing activities such as taking on various virtual nightlife-jobs including record store manager, promoter, or club bouncer in avatar form. Users can also buy different outfits for their avatars and various digital items in the record store and in the Telekom Shop with earned

[76] Renault Group launches the first industrial Metaverse - Renault Group global media website
[77] Fiat 500 (fiatexperience.it)
[78] Case Study: Volkswagen | SenseGlove
[79] Arthur D. Little (2022). The metaverse: What's in it for Telcos?
[80] Accenture (2022). Meet me in the Metaverse: The continuum of technology and experience reshaping the Communications industry

Beat Coins, a virtual in-experience currency that is earned by completing activities within Beatland[81].

Similarly, Orange, with its platform *Immersive Now*, and Vodafone, with *Vodafone 5G Reality*, are leading the development of virtual-worlds applications for hosting events and media content, as well as for opening own stores in virtual worlds[82].

### *3.3.6 Education*

Virtual worlds are expected to change the pace and quality of education. When it comes to training, they can provide new, interactive models, detached from traditional book-based methods, as well as to make the learning process more interactive and fruitful. Moreover, since virtual worlds are not limited in terms of geographical positioning, facilitating the process of bringing together individuals of diverse backgrounds can positively affect diversity in a virtual classroom.

[81] Telekom Electronic Beats to launch "Beatland" on Roblox | Deutsche Telekom
[82] Accenture (2022). Meet me in the Metaverse: The continuum of technology and experience reshaping the Communications industry

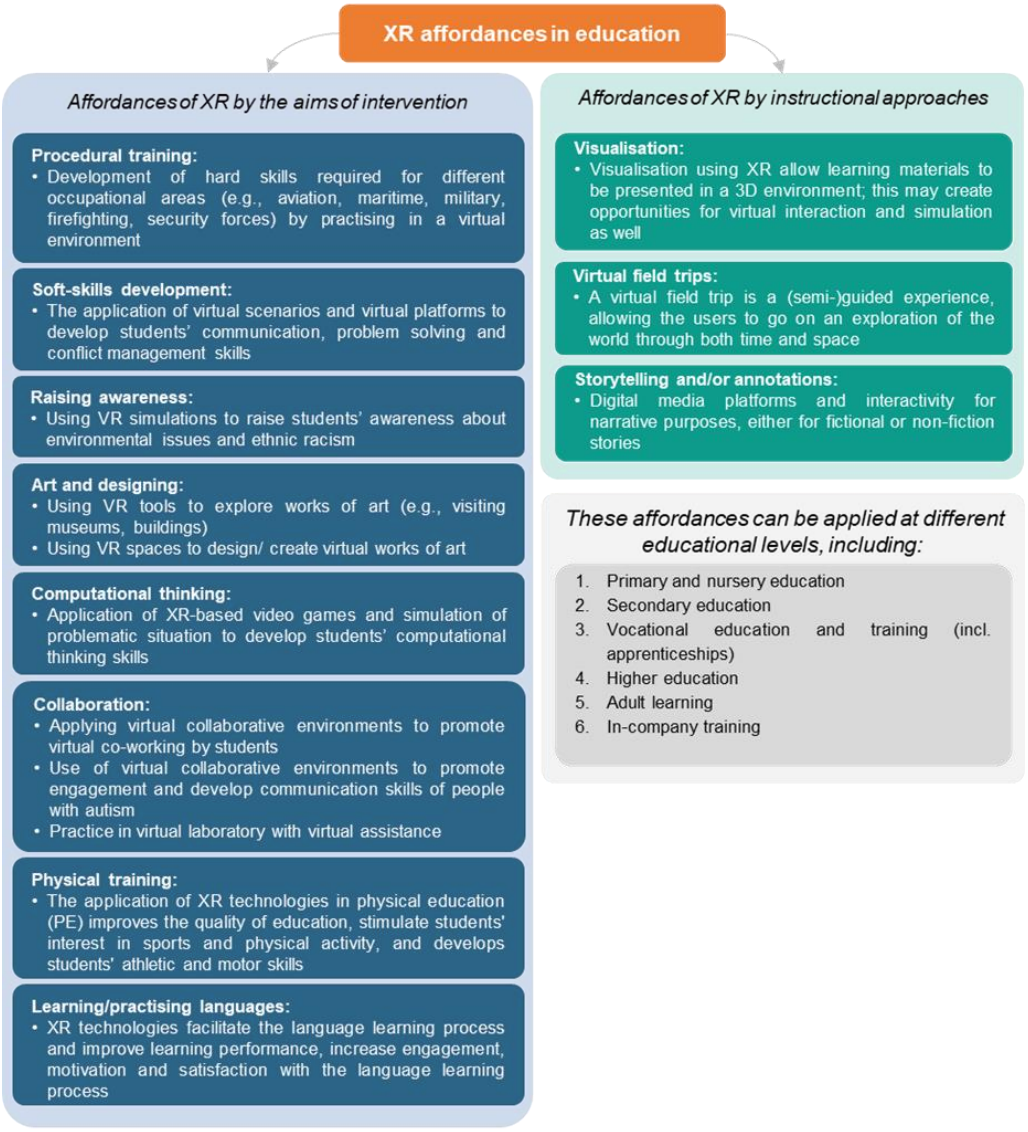


*Figure 8. XR applications in education.Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[83]

One specific application of virtual worlds in the education sector is the Finnish platform Lyfta[84], where teachers can find immersive content that can be used by their pupils in educational contexts. Content offered includes real-life stories in interactive 360 worlds, using VR and AR technologies as well as film content and other types of articles. The cross-curricular nature of the content makes it idoneous for teaching a wide range of subjects, from literacy to design & technology and science, to geography. Lyfta is used in over 700 schools over Europe and the US, and by over 2,500 teachers.

In Spain, the Basque University of Deusto in collaboration with the Spanish company Virtualware, opened in 2019 the *Laboratory of Immersive Technologies Virtualware-*

[83] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education
[84] Lyfta

*Deusto*[85] one of the first VR labs in the education sector. The lab allows students in the Engineering Faculty to access a dedicated space for research experiments. Students can also develop virtual and AR projects as part of university courses and in relation to several subjects.

The immersive potential of virtual worlds can also bring a different learning experience, and possibly better understanding of numerous topics. One example is the virtual reality exhibition *Nobody's Listening* on the genocide of the Yezidis, which was held in several countries, including Germany, in 2021. The exhibition was accompanied by a wider educational campaign in schools, in which students could access information and lessons about this historical event in a virtual environment with the use of VR glasses[86].

### *3.3.7 Health*

Virtual worlds can bring multiple opportunities to the healthcare system and there is high potential for XR to be applied more extensively in the medical field. For instance, it is expected that doctors will rely more heavily on AR technology for planning and performing surgeries. Virtual worlds can also be useful for performing virtual therapy and remote surgeries. In the future, AR holograms could play a leading role in medical training, which will improve communication efficiency between doctors and effectively replicate medical resources. VR/AR technologies are also enabling the representation of 3D structures, such as tissues or organs, facilitating more effective procedures and treatments. The benefits are reflected in more accurate and timely diagnosis as well as improved treatment outcomes. These technologies can bring considerable benefits for surgical intervention, such as a lower rate of errors and increase in efficiency. XR technologies allow for remote collaboration and telemonitoring, as well as hands-free image capturing via voice commands to maintain sterility during surgery.

[85] University of Deusto and Virtualware open the world's first VR Lab (virtualwareco.com)
[86] Bitkom (2022). A guidebook to the metaverse: Technological and legal basics, potential for business, relevance to society

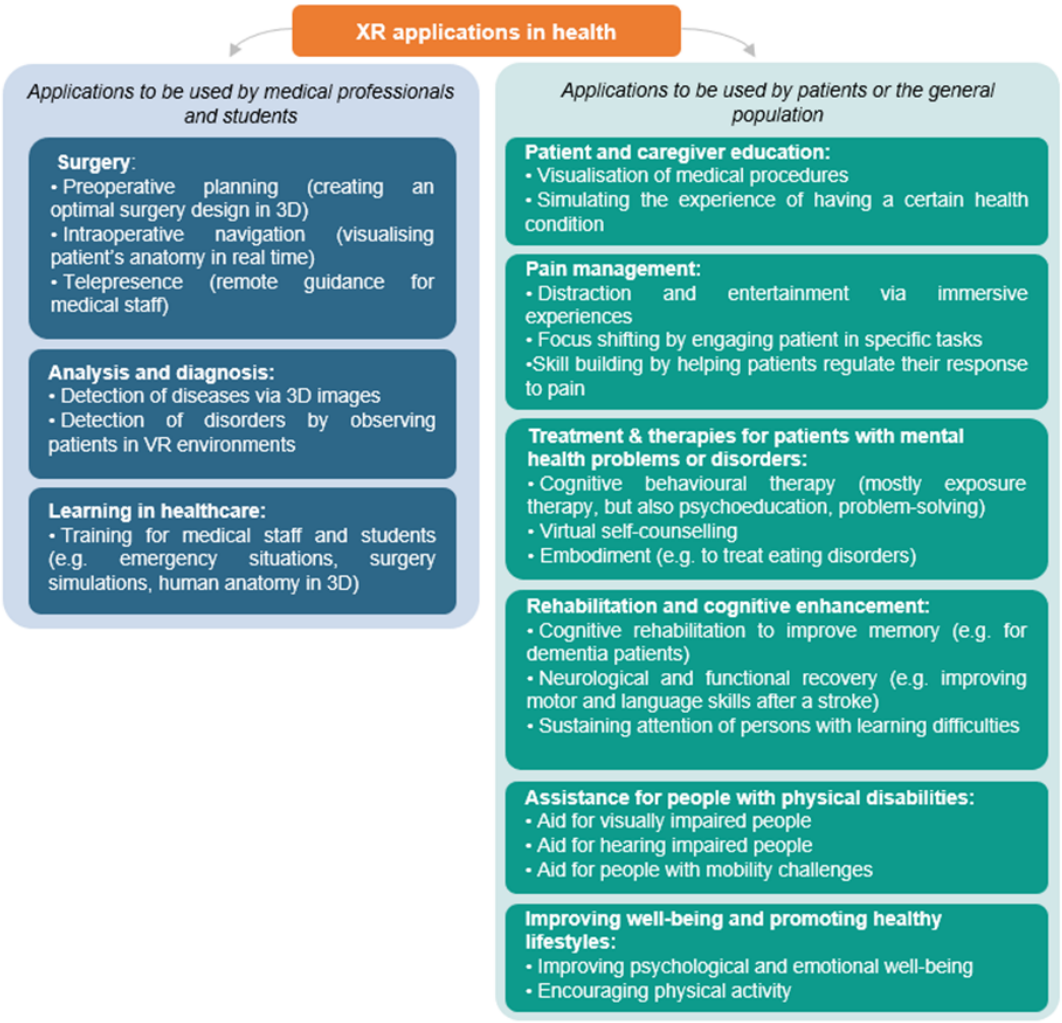


*Figure 9. XR applications in health. Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[87]

A relevant example, the *FollowKnee* initiative emerging from Brest, France, proposes an innovative workflow in Knee replacement surgery. It offers practical solutions throughout the process, including design, manufacturing, installation, and personalised follow-up of implanted prostheses. FollowKnee intends to transform knee treatment and patient care, from pre-operative to post-operative follow-up. FollowKnee uses mixed reality to allow a 3D model of the patient's knee to be projected onto their leg during surgery.

Similarly, SentiAR, as US-based start-up is developing an AR tool that can guide surgeons during cardiac and other invasive interventions. Using a VR headset, surgeons can see a 3D image of the patient's heart and the position of catheters. So far, experiments have demonstrated that this solution brings up to 50% improvement in point-navigation accuracy[88].

[87] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education

[88] Capgemini Research Institute (2022). Total immersion: How immersive experiences and the metaverse benefit customer experience and operations

The Vostars platform, stemming from the EU funded H2020 project with the same name, has released a surgical navigator that uses an innovative visor providing surgeons with the vision of the operating theatre with information about the patient or the organs involved. The augmented reality system is capable of an accuracy of less than a millimetre and it is the only truly wearable system available to surgeons[89].

### *3.3.8 Public administration*

Besides healthcare and education, virtual worlds can also be valuable tools for enhancing the quality and experiences in the public sector, in terms of administrative services offer, urban planning, voting and citizens' participation in decision-making processes, among others.

Such use-cases of virtual worlds in public services are being examined at both European and global levels, through public and public-private initiatives.

EU wide benchmarking of national investments in public procurement of innovative digital solutions[90] shows that there are significant differences in the speed of adoption across EU countries. However, some use-cases are already in place, indicating opportunities for facilitating public service provisions through such technologies.

One example is the City of Luxembourg, that created its digital twin, called "Megaverse". The establishment of the platform is the result of the private-public cooperation between the University of Luxembourg and the private company, Infinite Reality[91]. The platform is directed to the local actors, to "use the platform freely, fostering innovation, creation, and global responsibility"[92].

The first NATO operational 5G experiment for testing AR/VR solutions in the military field took place in Latvia, in November 2022, with the involvement of national public authorities in collaboration with private entities. The experiment was conducted by the Headquarters of the Supreme Allied Commander Transformation together with the Latvian Ministry of Defence, Latvian National Armed Forces enhanced Forward Presence Battlegroup, NATO Communications-Information Systems Group, NATO C&IAgency, mobile technology integrator LMT, and other industry players. As part of the experiment, VR, AR and 5G were used to optimise the way the technicians learn technical knowledge and skills, such as the remote piloting of military vehicles, and receive assistance from as many as several hundred kilometres away. Demonstration attendees also had the opportunity to witness virtual Joint Operations Centre pilot in action – its use across different communication networks and in virtual reality[93].

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[89] https://www.vostars.eu/

[90] https://digital-strategy.ec.europa.eu/en/library/benchmarking-innovation-procurement-investments-and-policy-frameworks-across-europe

[91] Research Luxembourg (2022). A future digital twin for Luxembourg in the Metaverse, Accessed online: A future digital twin for Luxembourg in the Metaverse – researchluxembourg.

[92] Research Luxembourg (2022). A future digital twin for Luxembourg in the Metaverse, Accessed online: A future digital twin for Luxembourg in the Metaverse – researchluxembourg.,

[93] Latvia holds the world's first NATO operational 5G experiment, testing AR/VR solutions in the military field | Aizsardzības ministrija (mod.gov.lv)

Outside Europe, the Seoul Metropolitan Government announced in 2021 “Metaverse Seoul”, a three-phase project planned to be fully implemented by 2026. The first component, which is currently ongoing, offer public administrative services including settling taxes, accessing official documents, issuing proof of citizenship, filing complaints, and providing youth mentoring or support centre for businesses. The second stage is anticipated for 2024 and it intends to include counselling and connecting foreign investors with local businesses. The third component would include extended reality technology for managing the city infrastructure[94].

The United Arab Emirates supported the development of the Sharjverse, the digital twin of the City of Sharjah, built on the Metaverse Lab platform and supported by the Sharjah Commerce & Tourism Development Authority. The plans for this metaverse are extremely ambitious. All the branches of city administration are to be transferred into virtual worlds. Additionally, Sharjverse would provide opportunities for virtually visiting the city for touristic purposes[95].

[94] D. Park (2023). South Korea lunches online metaverse replica of capital city Seoul to improve public services. Accessed online: South Korea launches metaverse replica of Seoul (forkast.news).
[95] S. Rapid (2022). Multiverse Lab launches Sharjahverse metaverse with government of Sharjah, UAE. Accessed online: Multiverse Labs launches Sharjahverse metaverse with government of Sharjah, UAE | Rapid Meta (rapidmeta.com).

# 4 TECHNOLOGICAL TRENDS - VIRTUAL WORLDS BUILDING BLOCKS

## 4.1 From the static web to the semantic web, and beyond

Since its creation in the 1990s, the Internet has been continuously evolving. The web of today is barely recognizable compared to its ancestor of 1991. The development of the web is often classified into stages: Web 1.0, Web 2.0, Web 3.0, now evolving into Web 4.0, the next transformative generation of the Internet.

Web 1.0 (1990s) is the first stage of the World Wide Web, with mainly static pages and embryonic human-computer interaction. Web2.0 (2000s), is an enhanced version of Web 1.0, with better usability and interoperability. Also called the social Web, Web 2.0 is a place where end users can generate their own content (i.e. podcasting, blogging, social media). Nevertheless Web2.0 remains centralised with user data owned and managed by the companies in charge of the web platforms.

Web 3.0 is a decentralised and AI-based web (2010s). In Web 3.0, end-users can create, share and connect content through search and analysis based on the capability to comprehend the meaning of words, rather than on keywords or numbers. Applications and programmes nearly never operate on a single server or store data in a single database, with users retaining control of their data. The 3rd generation of the World Wide Web evolves around decentralisation and tokenised economies. The rise of technologies such as blockchain, NFTs, decentralised autonomous organisations and virtual worlds is associated with the development of Web3. It introduces a new form of the Internet, based on peer-to-peer transactions, transparency and data democracy.

Web 4.0 is the next generation of the Internet physical and digital worlds will be seamlessly blending, enabling more intuitive and immersive experiences. Making use of advanced artificial and ambient intelligence, internet of things, virtual worlds and extended reality capabilities, distributed computing facilities, web and real objects and environments will be fully integrated and communicating between each other. In Web 4.0 end-users will have access to more personalised and interactive experience through more collaborative, decentralised and user-centred approaches. Special attention will have to be given to security, scalability and accessibility issues.

## 4.2 Virtual Worlds and Web 4.0

Virtual worlds are an important part of the technological transition towards Web 4.0, having the potential to enable more personalised immersive and intuitive user experiences. Although the concept of virtual worlds has been around for decades, they are now becoming technically, economically and socially feasible thanks to core technologies readiness and improved connectivity infrastructure[96].

A gradual technological shift is happening from the two-dimensional (2D) web, accessed through devices such as smartphones and tablets by traditional input and output interfaces,

[96] Hupont Torres, I., Charisi, V., De Prato, G., Pogorzelska, K., Schade, S., Kotsev, A., Sobolewski, M., Duch Brown, N., Calza, E., Dunker, C., Di Girolamo, F., Bellia, M., Hledik, J., Nai Fovino, I. and Vespe, M., Next Generation Virtual Worlds: Societal, Technological, Economic and Policy Challenges for the EU, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/51579, JRC133757.https://publications.jrc.ec.europa.eu/repository/handle/JRC133757

to a more generalised use of three-dimensional (3D) environments accessed through enhanced user interfaces, recreating virtual replicas of physical products, processes or systems, referred to as digital twins. The use of augmented, virtual and mixed reality devices in these 3D-enabled worlds will be more and more mainstream in the coming years, contributing to technological progress that is taking the internet to its next iteration, the Web 3.0 and further beyond, the Web 4.0.

Although the fourth phase of the Web is not clearly defined yet, it is acknowledged that it will enable more immersive and intelligent experiences. Virtual assistants will understand natural language and provide personalised replies and content. Smart devices will communicate to each other to perform complex tasks. Intelligent buildings will be designed to communicate with various integrated devices, such as security systems, energy management, and building automation. Similarly, connected autonomous cars will rely on a range of different sensors and embedded data processing and artificial intelligence capabilities to autonomously and seamlessly drive and interoperate and communicate with traffic management systems, roadside sensors, and other cars on the road.

Virtual worlds require multiple building blocks to create immersive and engaging experiences for users. Technologies such as extended reality, blockchain, artificial intelligence, data, edge computing, etc. have a key role as enablers of virtual worlds and the next transition shift, the Web 4.0.

This technological evolution will require the support of highly performing and resilient connectivity networks. The infrastructure of the future will connect earth networks (fibre, 5G and 6G) with space networks (satellite). This will bring together transmission, storage and computing, resulting into a computing continuum.

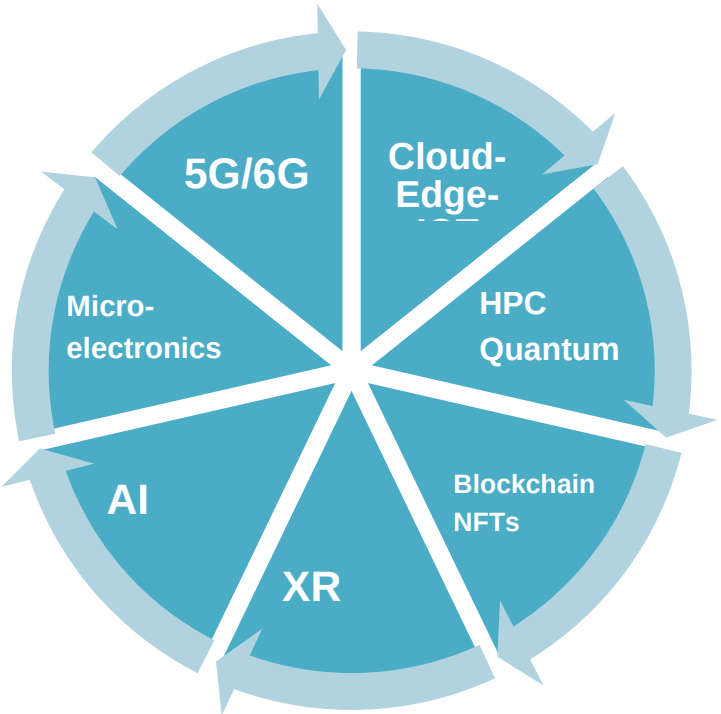

*Figure* ***Error! Bookmark not defined.****. Virtual worlds* enabling technologies. Source: European Commission

The next section outlines the various technological trends that constitute the main building blocks of virtual worlds.

## 4.3 Connectivity infrastructure

Connectivity and digital infrastructure are key enablers for Europe to take a leading role in the development of virtual worlds and will determine how fast virtual worlds can progress. Furthermore, connectivity is not only essential to the development of virtual worlds, but also for how users will perceive the experience.

In order support the development of virtual worlds with expected massive increase in data, networks need to transform radically from what we have today. Cloud technologies are vital for this development, but networks also need to be programmable and highly automated, able to combine different types of connectivity and integrating additional capabilities such as network slicing and edge computing resources. The connectivity requirements of virtual worlds and the future Web 4.0 will quickly exceed the distributed capabilities we have today. According to some estimates, even a modest use of the virtual worlds could drive a 20-fold increase in current data usage [97].

Networks also requires better quality and shorter data transmission delays in order to achieve well-functioning virtual worlds and to counter problems, such as cyber sickness[98]. Furthermore, virtual worlds also require networks with significant higher processing capacity.

Inclusiveness must be a key for virtual worlds, yet internet accessibility continues to be a pervasive issue. High bandwidth and latency standards need to be consistently upheld not only in wealthy urban centres, but also in rural or remote areas. This will require a sizeable investment in infrastructure. Moreover, for virtual worlds to deliver on its promise the internet connectivity must be available and affordable.

### *4.3.1 Networks*

According to Deutsche Telekom, the emergence of virtual worlds and metaverse-type applications will require new network capabilities and features, capable of managing the increasing data traffic as well as evolving requirements e.g., on latency and bandwidth.

In a recent report published by Analysys Mason[99] the authors emphasise that "the right infrastructure will be a key determinant of how fast the metaverse can progress". Networks will have to transform massively to support the development of virtual worlds. In particular, they will need to become cloud-native, programmable and highly automated, combining different types of connectivity and integrating additional capabilities such as network slicing and edge computing resources. Network operators such as Deutsche

[97] Credit Suisse (2022), Metaverse: A Guide to the Next-Gen Internet https://www.credit-suisse.com/media/assets/corporate/docs/about-us/media/media-release/2022/03/metaverse-14032022.pdf

[98] Cybersickness is combination of symptoms that occur in the absence of physical motion, it is similar to motion sickness.

[99] Analysys Mason, Network requirements for the metaverse (2023) Network requirements for the metaverse: towards 6G & the UDF (analysysmason.com)

Telekom, Telefonica, Vodafone or WINDTRE (who all contributed to the Call for Evidence – see annex) are considering network upgrades, new architectures and approaches to facilitate this transition to Web 4.0 as of primal importance for their current and future development.

### *4.3.2 5G/6G*

5G quality connectivity enables innovative digital services, 5G in healthcare, education, public administration and transport. By ensuring faster data-transfer speeds, low latency, wider coverage and greater network reliability, 5G technology is also expected to boost the take up of Internet of Things systems, and to add value to physical objects when connected and integrated into cloud solutions. European providers of 5G connectivity are leaders on the global market and participate in ambitious research programmes under the Horizon Europe programme.

The Commission funds[100] projects with budget from the Digital part of the Connecting Europe Facility to constitute examples of concrete 5G use cases[101]: they spark incentive for 5G-based developments.

The 5GSC Support Platform[102] is gathering good practices from 5G use cases, to facilitate replication of benchmarks for innovative applications also under other funding programmes across the Union.

The Digital Decade objective is 5G for all populated areas in Europe in 2030, but beyond this, advanced 5G is necessary wherever smart communities benefit from innovative services.

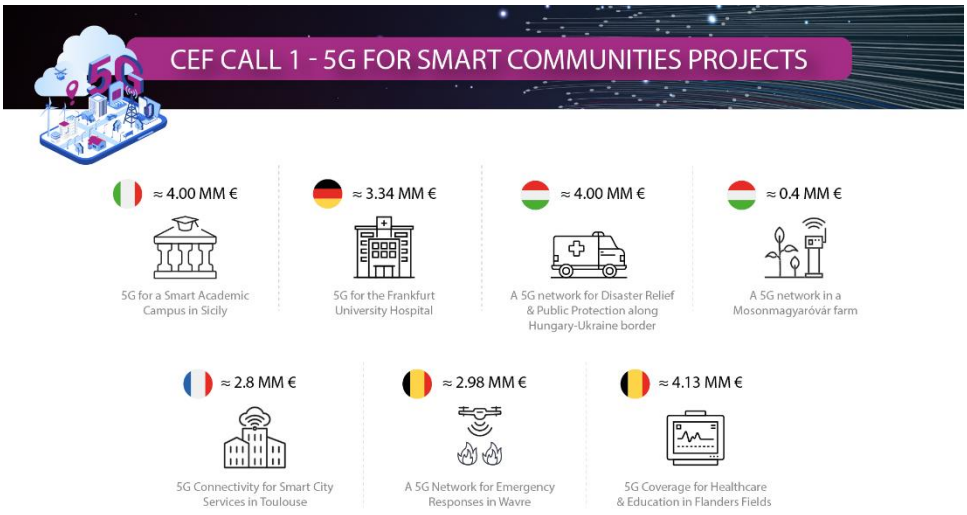


*Figure 10. Examples of projects where 5G enable virtual worlds:*

[100] 5G for smart communities | Shaping Europe's digital future (europa.eu)
[101] 5G for Smart Communities Support Platform - CEF Digital - Call 1 projects (b2match.io)
[102] 5G for Smart Communities Support Platform - Welcome (b2match.io)

- The 5G4ASSAC[103]project “5G for a Smart Sicilian Academic Campus” in Italy was granted a total EU contribution of EUR 4.005.551,18. It will implement a 5G Private Mobile Network to support new functional approaches to education and training in universities and hospitals, as well as the creation of a continuous care system. Vodafone (IT) together with the University of Palermo will run two use cases in the Health and Education domains to optimise both learning and training processes and to provide a solid basis for improving care methods.

## 4.4 Computing power

Virtual worlds will require enormous computational resources to support the real-time rendering of immersive environments, the processing of immense volumes of data and the management of millions of users and virtual objects.

The Cloud to Edge Continuum will provide seamless and trustworthy integration of diverse computing and data environments spanning from core cloud to edge to IoT and support the enormous data, processing needs and new resource types brought in by virtual worlds.

### *4.4.1 Cloud computing*

For massively scaled, shared, and persistent virtual worlds to operate well, they cannot rely on data stored locally as many video games do today. Instead, data must be cloud-streamed, thus requiring far greater bandwidth and lower latencies than we have now.

Cloud computing is expected to play a critical role in enabling the development and operation of virtual worlds and Web 4.0, providing the processing capacity and storage for delivering high fidelity, persistent, and synchronous experiences that update in real-time for millions of users. In this regard, the cloud will be an essential enabler for the hosting, scalability, and dissemination of immersive environments[104].

Cloud computing services need to provide on-demand access to computing power, storage, and networking resources, in order to enable virtual-worlds operators to scale up or down depending on needs, as well as, to offer advanced computing, AI and specific virtual world capacities widely.

Industrial market actors, such as Intel, anticipate that a mainstream uptake of virtual worlds would require computing capacities several orders of magnitude more powerful, at substantially lower latencies, and driven by a wide variety of device form factors[105].

In addition to their traditional compute and data services, cloud computing providers already offer additional services for the construction of virtual worlds. Public cloud services for digital twins now provide on-demand modelling and simulation services and tools that enable the development of digital twins of real-world systems with the goal of enhancing operations and performance, often in Industrial IoT scenarios. Additionally, cloud providers offer pre-trained models that facilitate the incorporation of AI features into user applications. Public Cloud Services for machine learning provide tools and services to make it easier for users to create their own machine learning models. At the

[103] 5G for Smart Communities Support Platform - 5G4ASSAC: 5G for a Smart Sicilian Academic Campus (b2match.io)
[104] IDC, Impact of Metaverse Workloads on Enterprise Infrastructure: AI and Cloud Computing Will Play a Central Role
[105] Intel, Powering the Metaverse, https://www.intel.com/content/www/us/en/newsroom/opinion/powering-metaverse.html

infrastructure level, to provide the best performance conditions for AI execution, public cloud providers increasingly provide accelerated compute units as a service. A major drawback of these solutions is that they bind the users to a specific ecosystem, not allowing for interoperability with services of other providers and raising concerns about data privacy and security.

To meet the expected computing and data needs of virtual worlds, it will be necessary to exceed current capabilities and seamlessly integrate the advantages of low-latency Edge computing into centralised Cloud models, **forming a Cloud-to-Edge Continuum** that offers transparent, secure and intelligent orchestration of interoperable centralised and decentralised computing and data environments.

### *4.4.2 Edge computing*

Edge computing enables the supply of data processing services from decentralised sites at the network's edge, minimising the transmission of unnecessary data over the network and improving the overall performance of cloud computing.

By embracing Edge computing technologies, the EU has a unique chance to meet the demand for the next generation data processing infrastructures, increasing its data processing capacity and reducing reliance on non-EU providers.

Artificial Intelligence drives the deployment of computer nodes and infrastructures at the Edge, as it enables faster processing of large volumes of data in a more secure environment. The demand for AI execution at the Edge has led to more sophisticated hardware processing architectures in Edge nodes and infrastructures. To cater for the performance requirements of AI processing, Edge nodes are progressively including, in addition to central processing units (CPUs), graphic processing units (GPUs), field-programmable gate arrays (FPGAs), as well as application-specific integrated circuits (ASICs)[106].

In terms of Edge solutions, two different segmentations of offerings can be observed in the Edge market: IoT Edge solutions, which focus on the provision of computing and data management services to IoT installations often enhanced with AI execution; and Telco Edge 5G deployments, for which accelerated processing architectures are of specific interest for some virtualised network functions.

With the proliferation of virtual worlds, the push towards more sophisticated Edge computing environments will intensify. Moreover, the demand for truly multi-user immersive experiences through advanced XR devices, will foster the development of on-device Edge technology.

However, merely relying on on-device and other conventional forms of Edge computing, or solely relying on cloud technology, will not meet the high demands for computing power, data access speed, and processing capabilities required by virtual worlds. These demanding requirements can only be fulfilled through an intelligent and simultaneous

[106] Edge AI hardware market - growth, trends, Covid-19 impact, and forecasts (2022 - 2027), https://www.mordorintelligence.com/industry-reports/edge-ai-hardware-market

combination of processing and data storage capabilities available at every stage of the continuum: on the device, at the Edge, and in the Cloud.

To explore the most effective approaches to Edge deployment capable of supporting the mainstream uptake of virtual worlds and Web 4.0, it is essential to consider multi-level and hierarchical IoT-to-edge-to-cloud management systems that address challenges related to resource availability and reliability, while also balancing the requirements of rapid response time, deployment costs, security, and energy.

### *4.4.3 High Performance Computing*

High performance computing (HPC) is expected to play a key role in the deployment of virtual worlds and Web 4.0 by providing the necessary capacity to support the massive amounts of computing power and storage that a mainstream adoption of these technologies will require.

On the one hand, the intensive demands of real-time interactions, simulations, and renderings required to deliver the complexity of the sensory modalities present in virtual immersive experiences will benefit from the capabilities of high performance and high throughput computing. On the other, virtual worlds featuring generative AI systems can strongly leverage on HPC computing power to train the AI models and run personalised virtual experiences for users.

Major players in virtual worlds and Web 4.0 technologies are strongly investing in expanding and advancing their HPC capabilities. Meta, for example, is experimenting with AI Research SuperClusters to power the massive computational power demands of their virtual worlds. This HPC infrastructure is a critical component in training the large AI models that enable user experiences. On a smaller scale, the UK supercomputing startup Hadean is developing a spatial-simulation engine supporting the connection of thousands of clients into virtual-world simulations, with applications such as training for operations on the field. EU supercomputers are also being used to power generative AI, like the EuroHPC LUMI system enabling research to produce large language models. Generative AI models are expected to be extended to other sensory modalities and have an even more relevant role in the development of virtual worlds.

A significant increase in the use of HPC technology for virtual worlds and Web 4.0 is expected as HPC systems achieve exascale and post-exascale performance.

Virtual worlds, which strongly rely on GPU-accelerated computing, will also benefit from both hardware and software improvements related to wider use HPC GPU accelerators on future supercomputing architectures. The future EU high-speed federation of HPC (including quantum computers) and data infrastructures should be a multiplier for such endeavours, by providing seamless access for the virtual-world research and industrial communities to the pool capacity of the EuroHPC supercomputers.

Disruptive advances involving virtual worlds and HPC can be anticipated in the coming years in diverse fields such as healthcare, weather, or education. In healthcare, virtualisation technologies could be used to plan complex operations by performing surgeries and medical treatments in a simulated and personalised virtual environment before the actual intervention. Similarly, simulation and rehearsal in virtual worlds could

improve response to natural or man-made disasters. In research and education, the immersive nature of the virtual worlds could provide new ways to collaborate, run simulations, visualise, and interact with large sets of information in real time.

The EU has supported the research and development of XR applications in recent HPC projects, mainly thanks to the opportunities arising from the increasing computational power of the European HPC systems. Several EU HPC centres of excellence present examples of such applications. For example, "CompBioMed", which is working on virtualising the human body for medical applications towards the creation of a Human Digital Twin, "PerMedCoE", where the virtual and augmented reality solutions have led to significant advances in healthcare technologies, "BioExcel", which used a virtualisation engine for molecules in order to explore and discover molecules in an immersive way, and "EXCELLERAT", which supported the development of 3D-simulation software able to illustrate combustion processes in virtual reality.

### *4.4.4 Quantum*

Quantum computing is currently used for optimisation of tasks in a highly efficient way. As virtual worlds will require large amounts of processing and modelling, Quantum algorithms might be used to improve the experience in these virtual environments. Furthermore, Quantum information technology could enhance security, protection of personal data and privacy in virtual worlds by improving the security of transmissions (using Quantum Key Distribution), and securing network channels, by providing an absolute randomness for virtual-worlds simulations (using quantum random number generation).

More specifically, Quantum technologies could play an essential role in virtual worlds as quantum computers can potentially process data much faster and more efficiently than classical computers, allowing for a more complex and realistic experiences. Quantum computing can help optimise virtual economies, supply chains, and marketplaces, making the virtual world more efficient and sustainable.

Quantum simulators, which have the same level of processing capacity as the quantum computers but for a specific task, can improve the realism and complexity of the virtual environments, including physics and chemistry simulations, leading to more immersive experiences in the virtual worlds. Simulations in virtual worlds could also be used to better understand quantum physics and potentially lead to new discoveries in quantum mechanics and related fields.

Privacy of communications will be a key element in virtual worlds. Quantum encryption can ensure safer and more secure communication and transactions. The concept of quantum entanglement and teleportation may inspire new ways of connecting and transporting information across different virtual worlds. Faster communication between different virtual worlds platforms could be possible with quantum networking, reducing latency and enabling seamless integration.

In the domain of Quantum technology, the main EU players are – inter-alia - PASQAL SAS (focused mainly on quantum simulators), AQT - Alpine Quantum Technologies

GmbH (focused mainly on quantum computing), QTI S.R.L (focused mainly on Quantum Communication)[107].

### 4.5 Data

The European strategy for data108, adopted by the European Commission in 2020, recognises the significant potential of data in shaping the digital landscape. Global data volume is expected to grow by 430% between 2018 and 2025, from 33 zettabytes to 175 zettabytes. This significant expansion presents new challenges and opportunities for the digital economy, including in Europe where the value of the data economy is projected to reach EUR 829 billion in 2025, up from EUR 301 billion in 2018.

Pursuant to the European Commission's vision for common European data spaces, to efficiently handle data, it is essential to combine two critical characteristics: a robust IT infrastructure and a comprehensive data governance framework that sets out the conditions under which data can be accessed and used. With respect to virtual worlds, the unprecedented surge in data generation presents significant technical challenges which require highly sophisticated computing infrastructure and advanced data management techniques. Traditional databases and processing and storage systems may not be sufficient to manage the scale and complexity of the data to be generated in virtual worlds. As such, emerging technologies, such as distributed databases, cloud and edge computing, may need to be leveraged.

Furthermore, virtual worlds will generate highly sensitive personal and non-personal data, making it crucial to address concerns relating to data security as well as the protection of personal data and the protection of privacy. Applicable personal data protection principles and rules should be upheld. These include fairness, transparency, allocation of responsibilities, and security. Digital technologies including, for example, (homomorphic) encryption, zero-knowledge proofs, differential privacy and federated learning, contribute to ensuring control over one's data. Various solutions already exist in the market, and the Commission has also been funding promising research and innovation projects through Horizon 2020 and Horizon Europe.

Deploying advanced infrastructure and ensuring data confidentiality and integrity, implementing strong access controls, and complying with relevant standards and regulations in virtual worlds will require significant investments. There are, however, massive opportunities for organizations seeking to innovate and create value therein. For example, by enabling the visualization of data spaces within virtual worlds, businesses can benefit from digital twins, allowing for the virtual testing of new products and services.

### 4.6 Digital Twins

Digital twins have been used primarily in industrial manufacturing and are now moving to many different sectors such as energy, transport, health, smart cities or climate change.

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[107] State of Quantum Computing in Europe: AQT pushing performance with a Quantum Volume of 128; https://www.aqt.eu/quantum-volume-128/

[108] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593073685620&uri=CELEX%3A52020DC0066

The data provided by these highly accurate digital simulations can be used in the development of virtual worlds and the deployment of Web 4.0. Looking ahead, digital twins will enable more efficient planning and prediction of needs, downtimes or prevent breakdowns.

To this effect, the European Union is investing in major initiatives such as Destination Earth (DestinE), the European Virtual Human Twin and the European Digital Twin of the Ocean (European DTO) and Local Digital Twins, to allow our researchers to advance science, our industries to develop precision applications and public policies to make informed public-policy decisions. Taken as a whole, such publicly funded digital twins represent an immense reservoir of resources for virtual worlds and Web 4.0.

### *4.6.1 Destination Earth (DestinE)*

To boost the EU's ability to predict and manage environmental disasters, the European Commission brings together under the Green Deal European scientific and industrial excellence to develop a very high precision digital model of the Earth, DestinE[109]. This digital twin will fully integrate observations with an Earth system model and human subsystems for e.g., water, food and energy resource management, to assess the impacts on, and influences from, these subsystems on Earth system trajectories. The twin would allow to assess possible changes and their causes consistently across local and global spatial scales and over timescales stretching from days to decades.

DestinE was kicked off in December 2021 and aims to develop in the first phase of the initiative until mid-2024 for a wide range of end-users from policy services, science and the general public a series of different applications and services in relation to two key thematic areas:

- Extreme weather monitoring for a better identification of expected weather-induced harmful impacts and their location in time and space before they occur.
- Predicting effects of climate change and developing climate change adaptation strategies (as part of the EU's Mission on Adaptation to Climate Change[110]).

These developments are undertaken on behalf of the European Commission by three implementing institutions – ESA, ECMWF, EUMETSAT – together with a substantial number of scientific and business institutions in Member States. A first version of the DestinE platform, including the first two digital twins for climate change adaptation and extreme weather events, powered by the European High Performance Computing Joint Undertaking (EuroHPC JU)[111], is expected to go live in mid-2024.

By the end of the decade, the aim is to achieve a convergence of the different simulation and modelling services and applications towards the ultimate goal of building a digital replica of the planet from the interactions of its key physical and socio-economic systems.

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[109] https://digital-strategy.ec.europa.eu/en/policies/destination-earth
[110] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/adaptation-climate-change_en
[111] https://eurohpc-ju.europa.eu/index_en

DestinE goes beyond current sustainability policy decision support tool development initiatives on both EU and Member State levels (e.g., Copernicus) by significantly increasing the levels of precision (down to km scales at global level) as well as inclusion of impact sectors and user-defined scenarios building capabilities.

To ensure consistency of developments and sharing of best practices, DestinE is closely linked to Member State initiatives in the area and, representing an open digital infrastructure, ultimately aims to integrate other initiatives, best practice models and data resources.

### *4.6.2 European Digital Twin of the Ocean (EU DTO)*

The European Commission's vision for the European Digital Twin of the Ocean (EU DTO) is encompassing the development of a digital platform to make ocean knowledge [112] readily available to people, entrepreneurs, scientists and policy-makers and to provide them with an innovative set of user-driven and interactive digital tools. The EU DTO is envisioned as an operational public service that will support society's shared responsibility towards "the conservation of the global ocean and its resources, towards the restoration of marine and coastal habitats and towards the development of a sustainable blue economy", by enabling knowledge-based decision making and substantive societal engagement.

The EU DTO will provide powerful tools to strengthen marine knowledge and its utilisation to achieve the goals of the "Mission Restore our Oceans and Waters by 2030"[113] and the Green Deal objectives. It will support authorities in Member States to better implement the EU Marine Strategy Framework Directive (MSFD), the Common Fisheries Policy (CFP), the Maritime Spatial Planning Directive (MSPD), design climate adaptation etc. and will be able to contribute in assessing the results policies of international policies as the Treaty on marine Biodiversity Beyond National Jurisdiction (BBNJ). Additionally, it will be utilised by businesses to develop decision support tools relying on ecosystem-based management; and it will be used by people to encourage local actions, contributions to the observing systems, ocean literacy and more.

The EU DTO will comprise of a core public infrastructure providing the digital foundation to the different applications that will contribute to the overall endeavour. The development of a core public infrastructure will ensure the consolidation of all European action in a common digital framework, continuity and maintenance of legacy of the contributing actions as well as, increased added value from the existing investments of the EC in marine knowledge. This core EU DTO infrastructure will include:

a) **a data lake**, bringing together the open and interoperable marine data already available through European Commission services (Copernicus Marine, European Marine Observation and Data Networks (EMODnet), marine European Research Infrastructure Consortiums (ERICs), etc.) and ensuring the conditions for the future streamlining of data from other sources (social and economic; deriving from businesses; fisheries related, etc.).

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[112] Ocean observation, marine and socio-economic data, mutli-disciplinary models forecasts, information from the assessment of models, artificial intelligence applications and more knowledge-based tools.

[113] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters_en

Data and ocean observation are a key component of the DTO as they provide the foundation in which all other applications will build and determine the level of accuracy of models;

b) **a set of underlying ocean models**, based on the existing operational ocean forecasting and ocean climate services provided by Copernicus, which will allow users to connect their own applications, develop "local twins" and assess a variety of scenarios based on their needs;

c) **a DTO engine** which will enable, among other services, the use of cloud and high-performance computing (HPC) capabilities, to configure and run models and relevant applications, initially from a variety of research and innovation actions and in the future from all users across the marine value-chain;

d) **a co-working environment** which will allow access to the aforementioned and enable the development of digital knowledge services by any user for any purpose, including private, marketable applications.

The prototype of the core EU DTO infrastructure, encompassing the first version of the above-mentioned elements, is a commitment of the current Commission through President von der Leyen[114]), and will be delivered by the end of 2024, including at least two demonstrators to showcase its added value in practice. The core EU DTO infrastructure will follow standards that will enable its interoperability with the Destination Earth infrastructure of the Digital Europe Programme. This will ensure keeping open the collaboration pathways between the two initiatives in the future, ensuring the ability to develop integrated applications based on different elements of the planetary system.

### *4.6.3 European Virtual Human Twin*

A virtual human twin (VHT) is understood as a computational model of human patho-physiology and related processes at different levels of human anatomy. VHTs have been shown to have very significant potential in healthcare and life sciences, by delivering on personalised care, from targeted prevention to tailored treatments and clinical pathways, supporting healthcare professionals from medical training, surgical intervention planning and other applications in virtual worlds and Web 4.0 environments. They can make a significant contribution to achieving the goals of the European Health Union.

The European Virtual Human Twin project named EDITH[115] is a Coordination and Support Action funded under the Digital Europe Programme, which capitalises on the development of digital technologies, HPC availability and access to research and healthcare data in Europe. The project will define a roadmap to progress from standalone single organ and organ system models to data and knowledge-driven fully integrated multiscale and multi-organ whole-body twins. EDITH facilitates this process by building an evolutionary ecosystem, driven by consensus among the relevant European communities of practice, supported through practical tools such as a VHT resources repository, and an outline for a future a co-simulation platform.

[114] https://ec.europa.eu/commission/presscorner/detail/en/speech_22_962
[115] https://www.edith-csa.eu/

The work of EDITH is expected to prepare the basis for the further evolution of VHTs by growing an inclusive VHT ecosystem within the EU Member States and associated countries. This starts with a comprehensive mapping of existing relevant actors, initiatives, resources in terms of models, data sets, methods, good practices, infrastructures, solutions, services, and the barriers in further developing VHTs. Clinical representation will be ensured while fostering closer collaboration among relevant stakeholders such as solution developers, technology and infrastructure providers, end-users (healthcare professionals, patients), regulatory organisations, and Health Technology Assessment bodies.

EDITH will provide a VHT roadmap with all necessary conditions for evolving towards an integrated VHT, identifying the necessary building blocks to ensure VHTs' clinical application and formulating clear, near and mid-term policy recommendations. It will also address interoperability, computation and storage needs, and health information integration from various sources. The roadmap will identify implementation needs and barriers, including the development of a strategic approach for VHT's clinical deployment, fostering uptake of personalised clinical decision-making, with a particular focus on unmet medical need.

EDITH will further develop a federated, cloud-based repository of VHT resources including data, models, algorithms, and good practices. This will provide a first virtual collaboration environment for multiple users and organisations pooling existing VHT resources across Europe. Ecosystem actors will create a catalogue with and enlist available resources in the repository. A federated approach will see links established with ongoing projects and initiatives with complementary objectives related to health data spaces (e.g., genomics, cancer imaging) and cross-border connectivity.

### *4.6.4 Local Digital Twins*

According to the World Economic Forum Global Digital Twin Cities Report 2022[116], the Local Digital Twin market is growing at a 58% compound annual growth rate with a global estimate of 48.2 billion dollars market value. Local Twin technology combines numerous technologies to deploy full-scale digital versions of real-world physical entities, objects and processes and create digital simulation models that can be updated and changed as their physical equivalents change. This pairing of the physical and digital worlds provides behaviour modelling and real-time monitoring, through integration of different and disparate data sources, that change the way cities are planned, operated, monitored, and managed. Communities and public authorities in Europe are progressively rolling out Local Digital Twins[117] by digitalising and interconnecting data sources in an interoperable manner through urban data platforms. The United Nation World Cities Report 2020[118] highlights the opportunities provided by the large amount of data collected in cities (sensors/IoT, smart objects, smartphone apps, social media, etc.), that can be analysed to foster real-time monitoring, scenario-planning, disaster simulation and automation of

[116] https://www.weforum.org/reports/digital-twin-cities-framework-and-global-practices/
[117] https://www.degruyter.com/document/doi/10.1515/auto-2021-0083/html?lang=en
[118] https://unhabitat.org/sites/default/files/2020/11/world_cities_report_2020_abridged_version.pdf

various municipal services in the run towards environmentally sustainable city planning and service delivery.

At Digital Day 2021[119], European Union Member States committed to work with local authorities and other relevant stakeholders to set up a European network of Digital Twins of the physical environment and support EU cities and regions to use green digital solutions in their transition to climate neutrality. The Commission is encouraging the adoption and scale up of AI-based digital twins by investing in open solutions and facilitate their deployment through the Digital Europe Programme.

The following are relevant examples of case studies of local digital twins in the EU:

- The **Rotterdam Digital Twin**[120] will act as a platform for a new era of digital city applications. It can support Rotterdam's waste services; equipping community waste bins with sensors will inform urban waste collection companies about how full waste containers are, so they can optimise their routes based on the areas that need collection most.
- The **Digital Twin of Rennes Metropole**[121] developed by Dassault Systèmes enables planners to prioritise new development along efficient and underutilised transport lines, while identifying routes where congestion and high service usage makes new development less desirable.
- The project **smartBRIDGE**[122] was initiated by the Hamburg Port Authority, which is responsible for operating Kohlbrand bridge. Kolhbrand bridge is the backbone of Hamburg's mobility network and Germany's second longest road bridge, but the city is growing and so is the strain on the aging bridge, which needs constant monitoring. Conventional bridge inspection and maintenance is responsive, reacting to problems when they happen, but through the bridge's digital twin it is now possible to have predictive maintenance. The local Authority now have permanent access to the bridge condition and can simulate all the variables that influence it, optimising its management and avoiding problems that could hinder the safety of the bridge or disrupt traffic.
- The **Digital Twin of the Port of Antwerp and Bruges**[123] is a digital copy of the port area with real-time information: which ships are in which locks and docks? Are all the life preservers hanging in their closets? How much energy are our wind turbines producing? This technology also supports port employees in doing their jobs more efficiently and pleasantly. As a result, they can monitor moorings more accurately, detect incidents more quickly, etc. This all benefits safety and smooth traffic flow in the port.

In addition, Barcelona and Bologna have made an agreement with two of the three most powerful supercomputers in Europe (MareNostrum, LEONARDO), the Barcelona

[119] https://digital-trategy.ec.europa.eu/en/news/eu-countries-commit-leading-green-digital-transformation
[120] https://smart-cities-marketplace.ec.europa.eu/news-and-events/news/2019/rotterdams-digital-twin-redefines-our-physical-digital-social-worlds
[121] https://www.ecocites.logement.gouv.fr/IMG/pdf/ecocite_fiches_top_10_2019_rennes_metropole_pia_bat_en.pdf
https://www.3ds.com/insights/customer-stories/rennes-metropole
[122] https://www.homeport.hamburg/portfolio/smartbridge
[123] https://www.portofantwerpbruges.com/en/our-port/port-future/smart-port

Supercomputing Centre (BSC-CNS) and the CINECA Consortium of Universities, along with the University of Bologna, to develop an evidence-based public policy model through the construction of local digital twins. One of the uses will be to help with the city's planning and the objective to implement the 15-minute city concept, which proposes people have access to all the services they need within a 15-minute walk or bike ride from their home.

In the future, the more advanced Local Digital Twins will incorporate virtual world solutions as natural interfaces to deploy CitiVerse technologies at different levels. In conjunction with urban platforms, cloud infrastructures and the power of High-Performance Computing, new simulation algorithms and AI services fuelled by big data from different sources will be provisioned supporting citizen's participation and exploration of such hybrid worlds.

### *4.6.5 European electricity grid digital twin*

Digital twins are already being used to model parts of our electricity system, at different levels. For instance, the Net2DG Horizon 2020 Project has led to the development of an ICT-Gateway that enables a digital twin of the low voltage distribution grid. On top of this digital twin, some applications for Grid Monitoring, Loss Calculation, Outage Detection and Diagnostic have been developed. Overall, this architecture leads to a fully digital process for operation and planning of the low voltage grid.

Another example, at a more local level, is the Finnish transmission system operator, Fingrid, which implemented a digital twin to help manage its assets and operations and plan its infrastructure investment. This digital solution allowed Fingrid to reduce data collection workload and focus on data analysis. The model provided by the digital twin allows Fingrid to plan investment up to 25 years in advance.

Going further, the Commission's action plan for the Digitalisation of the energy system[124] announced an EU "digitalisation of energy" flagship initiative, in the form of Commission's action in support of the creation of a digital twin of the European electricity grid. The aim is not only to help optimise operations management and network development planning, but also to streamline renewable integration analysis, synchronise data from various sources across the value chain, and generally strengthen the visibility and controllability of the grid. The Digital Twin of the European electricity grid will also make it possible to investigate and assess how the electricity grid responds to stimuli or shocks (e.g. renewable energy sources integration, demand response and cyberattacks) using forecasting and long-term modelling, and thus contributing to a more resilient electricity grid. To achieve these objectives, investments need to be coordinated across the following five areas: (i) observability and controllability; (ii) efficient infrastructure and network planning; (iii) operations and simulations for a more resilient grid; (iv) active system management and forecasting to support flexibility and demand response; and (v) data exchange between TSOs and DSOs.

[124] COM(2022) 552 final

On 20 December 2022, as a first step towards the establishment of the Digital Twin of the European electricity grid, the European Network of Transmission System Operators for electricity (ENTSO-E) and the association of European distribution system operators (EU DSO Entity) signed a declaration of intent on the digital twin of the electricity system, with the presence of Commissioner Simson[125]. This declaration of intent builds on the cooperation framework established in a Memorandum of Understanding between the two associations signed in January 2022 and confirms ENTSO-E's and the EU DSO Entity's willingness to cooperate to develop this digital twin. The Commission will closely follow-up the progress of these commitments with ENTSO-E and the EU DSO entity and will further support the development of the digital twin of the European electricity grid with a Horizon Europe call which will be awarded over the course of this year.

## 4.7 Distributed ledger technology – Blockchain

A distributed ledger system, also known as a blockchain, enables transactions to be validated and recorded across a network of computers, rather than on a centralised server. This provides increased security, transparency, and immutability to the transactions that take place within virtual worlds. This distributed ledger system can be useful for managing virtual assets, such as virtual currency or virtual real estate, and it can allow for secure, transparent transactions within the virtual worlds.

### *4.7.1 Blockchain*

Blockchain is one of the key foundational technologies for Web 3.0 and for emerging virtual worlds. Known as the technology of trust, it enables large groups of people and organisations that may not know or trust each other to agree on and permanently record information without the need for a third-party authority.

Open and permissionless blockchains will play a key role in the open virtual worlds. In the open virtual worlds, the essential decisions and processes needed for its functioning are decentralised by using blockchain technology.

The European Blockchain Observatory and Forum, a European Commission initiative to accelerate blockchain innovation and the development of the blockchain ecosystem within the EU serves Europe's efforts in this transformative new technology[126]. Furthermore, the European Blockchain Services Infrastructure (EBSI)[127] leverages blockchain to create cross-border services for public administrations, businesses, citizens and their ecosystems to verify information and make services trustworthy.

### *4.7.2 NFTs*

A non-fungible token (NFT) is a unique and non-interchangeable unit of data stored on a digital ledger (blockchain). NFTs can be associated with reproducible digital files such as photos, videos, and audio. NFTs use a digital ledger to provide a public certificate of

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[125] https://energy.ec.europa.eu/news/commission-welcomes-cooperation-between-entso-e-and-eu-dso-entity-digital-electricity-grid-twin-2022-12-20_en

126 https://www.eublockchainforum.eu/

127 https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home

authenticity or proof of ownership, but it does not restrict the sharing or copying of the underlying digital file. The lack of interchangeability (fungibility) distinguishes NFTs from blockchain cryptocurrencies.

NFTs consists of an identification code (to identify the token) and metadata (indicating what the NFT represents). NFTs are powered by smart contracts that run when predetermined conditions are met (e.g., when the NFT is created or sold, smart contracts record the metadata, assign the ownership of the token and ensure that the information stored is transparent and immutable).

In virtual worlds, non-fungible tokens are expected to contribute to the facilitation of the commercial transactions. NFTs are considered a particularly useful technology to track and validate the sale and ownership of digital goods in a virtual space. In virtual worlds and virtual markets, digital assets are expected to be tokenised with fungible, nonfungible, hybrid or composable-NFT tokens. Virtual worlds are expected to build up a fundamentally new economy focusing more strongly on NFT markets and creator economies.

NFTs are being used in a wide variety of applications. This is especially notable in the CCIs, as they facilitate innovation in content creation, and open up opportunities for artists and creators to access new, alternative business models and new audiences. For instance, digital arts have gained popularity embracing the features of non-fungible tokens, including the proof of ownership, immutability and provenance tracking. NFT platforms connect artists and creators directly with potential buyers and audiences, in some cases with lower association cost and provide them with an opportunity to directly showcase their artwork to the public through virtual NFT art galleries and exhibition spaces. In fact, NFTs have already been introduced in new practical business models, such as certifying the physical ownerships of the luxury goods in virtual worlds. NFTs can also be used in other industries, such as sports, fashion, gaming and music with use cases such as record sales and event ticketing. Other applications are found in supply chain and the logistics sector, where NFTs are used for ensuring the authenticity and tracking the ownership of products.

## 4.8 Extended reality

Extended reality (XR) technologies, such as virtual reality (VR), mixed reality (MR) and augmented reality (AR), play important roles in the development and uptake of virtual worlds. These immersive technologies enable users to interact with digital environments and objects in a more natural and intuitive way. Moreover, truly immersive virtual worlds would benefit from being experienced through VR or AR glasses or visors rather than traditional smartphones, tablets and PCs.

### *4.8.1 Virtual reality and augmented reality*

Virtual and Augmented Reality (VR/AR) are opening new ways of experiencing and communicating with our environment, and between ourselves. They have the potential to

disrupt many sectors: manufacturing, health, education, cultural and creative industries[128],e, engineering, entertainment, live events, retail or construction.

The social distancing and global lockdown imposed by the COVID 19 crisis, as well as climate and environmental concerns, have accelerated the need for the development and the adoption of interactive and immersive technologies, with the goal to boost the productivity of remote and online contactless activities.

AR and VR can provide solutions to tackle the needs industry and society are facing nowadays, for example by making expertise available remotely, thus boosting efficiency, reducing costs and eliminating physical distances while increasing the access of users.

AR and VR, which are often referred to as eXtended Reality (XR), are an important components of an immersive experience. For a more realistic and efficient experience, interactive technologies as a whole have an important role to play (also including haptics, speech, computer vision, etc.). It is also a highly multi-disciplinary field where the role of social science and humanity experts is crucial.

Nowadays VR technology is much more mature, with both tethered and standalone devices providing greater processing power and better sensors, faster refresh rates and higher resolutions. However, despite these improvements, wearing a VR headset for an extended period of time can still cause discomfort, and users may feel isolated from their surroundings while using it. Future iterations of VR may address these concerns and make the experience even more enjoyable for users.

AR and haptic technologies, on the other hand, still suffer from technical limitations that prevents them from mass adoption. The development of these technologies is inevitable, but questions exist over how quickly and cost effectively hardware manufacturers can overcome remaining challenges and whether VR/AR adoption is necessary for the proliferation of virtual worlds as PCs and smartphones may provide immersive experiences as well.

Virtual reality and augmented reality are the key technologies when it comes to innovative immersive experiences. Building on the academic definition of the reality−virtuality continuum (see figure x), it is possible to picture a spectrum where the real world and VR (i.e., a fully digital immersive environment) are at its extremes, while AR positions in the middle (i.e., blending digital content with the real environment).

[128] *Advanced Technologies for Industry – Sectoral Watch Technological trends in the creative industries*. 2021 Available at: https://ati.ec.europa.eu/reports/sectoral-watch/technological-trends-creative-industries

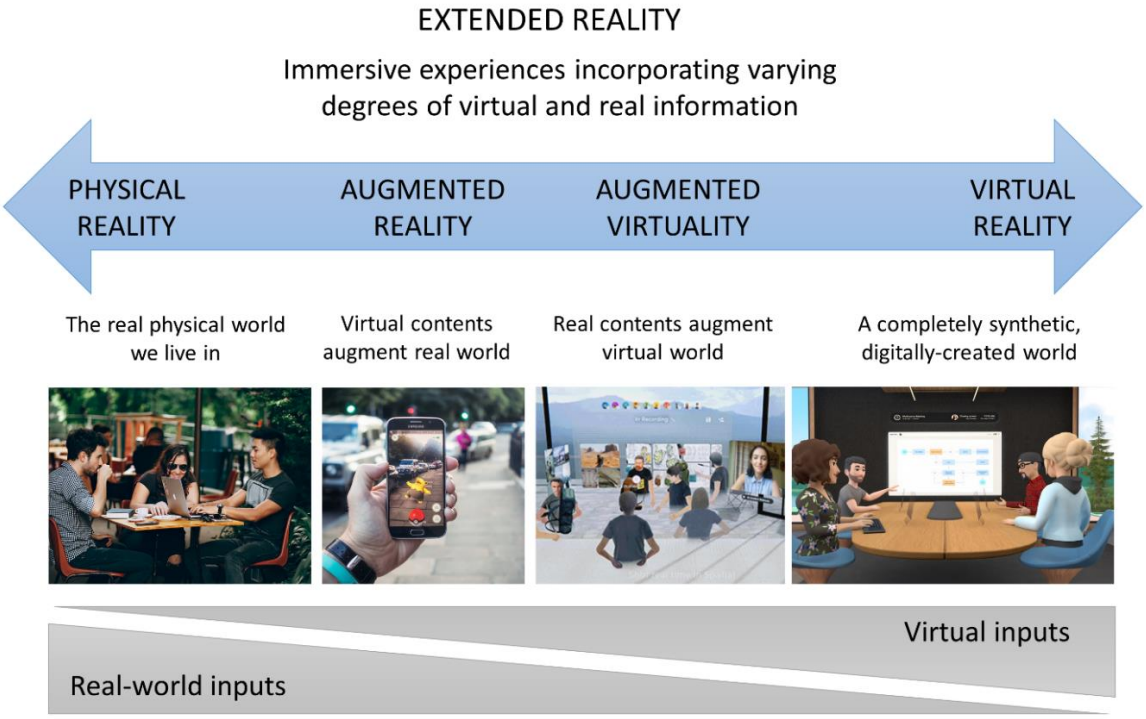


*Figure 11. The reality–virtuality continuum*. Source: JRC[129]

The general forward momentum of VR/AR technologies can be explained by looking at two main issues:

- the ongoing technological developments, which make VR/AR technologies more accessible, more comfortable, and cheaper;
- the increasing awareness of the potential and benefits of VR/AR in a wide range of areas – not only in entertainment but in many industry verticals and consumer markets.

VR/AR is also proving to be useful in many application areas and mature enough to become the navigation technology of the future. This trend is highlighted by the cross-sectoral nature of the technology, as well as its close relationship with other emerging technologies, such as artificial intelligence (AI), the Internet of Things (IoT), big data analysis, 5G, and robotisation. The relation of VR/AR to these technologies is different, also depending on the application considered. For instance, AI can enhance and optimise tools used to create VR/AR content, while 5G enables higher-quality and faster streaming of VR/AR. In many other cases, VR/AR's innovativeness does not stand in the specific content created through it, but in the way it can revolutionise user–machine interaction, potentially making it the navigation tool of the future.

[129] https://publications.jrc.ec.europa.eu/repository/handle/JRC133757.

### *4.8.2 Challenges for European AR/VR technologies*

The **cost** of hardware remains a barrier. A good headset includes motion sensors and eye tracking devices. Europe is at the forefront developing lightweight headsets that could be used for a longer period of time, but they are still costly (from 600 to 6000 EUR).

The lack of **bandwidth** is an issue for the use of AR/VR on the go; the future development of 5G will most probably create a boom in XR applications.

The lack of widely accepted **standards** lowers compatibility between systems and slows down the development process and increases design and testing costs. **Openness and interoperability** in XR technologies (and in virtual worlds and Web4.0) are two features that will depend on the governance model. To foster innovation and creativity, this governance model should enable diverse participation, including the representation and participation of vulnerable groups by promoting inclusivity and accessibility. Several initiatives are trying to devise the industry standards at a global level as explained in section 4.14 on standards. However, European players are underrepresented in existing initiatives, which are mainly US based such as OpenXR (see section 4.14.2).

The re-use of content in order to create AR/VR environments needs to follow **intellectual property rules** such as copyright. It might prove to be an issue for start-ups or SMEs (access, costs, compliance with law). Moreover, the generation of content needs to comply with **personal data protection rules**

Lack of **skills** among staff is expected to become a hurdle when introducing VR/AR to industry. In order to introduce and maintain such applications or provide modelling for processes, staff needs the appropriate skills at an engineer's level.

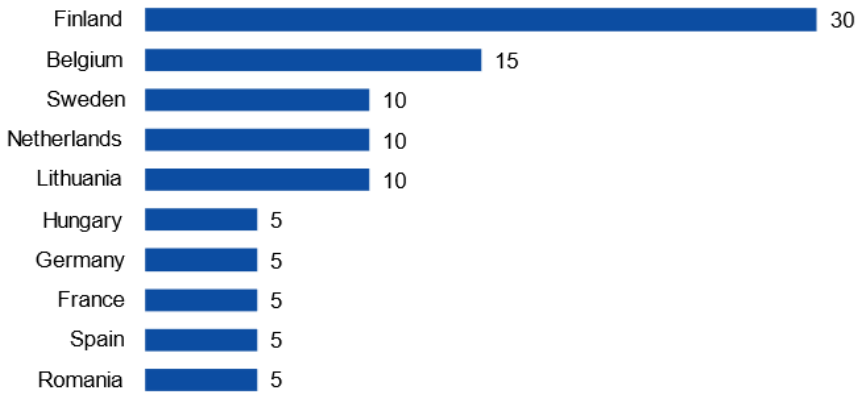


*Figure 12. Overview of number of universities that provide XR education in Europe. Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[130]

A survey was distributed to over 150 universities across Europe, with the vast majority of those targeted coming from Finland, followed by Belgium.

[130] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education

While VR might look safer to the user as it is a fully computerised 3D image or environment that can be enjoyed from the comfort of an armchair at home, it still has a large potential to cause accidents. The AR environment takes place in the real world with digital additions, such as in apps and games where the user follows a specific path set out by the digital world increasing the risk of accidents in the real world (ex. Pokémon Go). For this very reason, the automobile industry is reluctant to embrace XR technologies. The long-term **health issues related** to VR are not well documented. Nausea is one side effect, which is reasonable well documented and occurring in some people.

### *4.8.3 3D technology*

Three-dimensional (3D) technology plays a crucial role in the development of virtual worlds, as it helps to create a sense of immersion, allowing users to experience a virtual environment that feels real and responsive. 3D models are used to create virtual objects, buildings, landscapes and characters. Moreover, 3D is also essential in the creation of avatars and digital representations of users in virtual worlds.

There are two main techniques to create digital 3D representations of real-world objects or environments: 3D modelling and 3D acquisition. 3D modelling provides greater control over the final output, while 3D acquisition is generally faster and more accurate in terms of capturing real-world details.

3D modelling involves using specialised software to manually create a 3D object from scratch. The designer uses a combination of tools and techniques to add shapes, colours, textures, and other details to the object until it accurately represents the desired object. This process can be time-consuming and requires a high level of skill and expertise in 3D modelling software. There are many 3D modelling techniques and the choice of technique will depend on the artist's skill level, the complexity of the model and the desired outcome. Some common 3D modelling techniques are polygonal modelling, NURBS modelling, 3D sculpting, procedural modelling, paramedic modelling, and box modelling.

On the other hand, 3D acquisition involves capturing the geometry and appearance of a real-world object or environment using specialised hardware and software. There are two types of 3D acquisition methods: active and passive. Active methods use directed radiant energy to mark a point in space, whereas passive methods record the reflected radiation from a surface. Active sensors are typically terrestrial laser scanners, structured light scanning systems and range cameras. Passive or image-based documentation systems include (cameras) aerial photogrammetry (satellites, aircraft, and UAVs), terrestrial photogrammetry, and close-range photogrammetry. These systems capture the surface geometry of an object as well as the surface texture.

A multi-view 3D reconstruction is another process for generating a 3D point cloud (and model) from several overlapping images, using robust automated algorithms. The resulting 3D models are appropriate for metric information extraction for visualisation purposes in virtual-worlds applications. Passive methods include studio image acquisition, uncontrolled environment image acquisition and video frames extraction.

LiDAR and photogrammetry are two 3D acquisition technologies identified by the Study on quality in 3D digitisation of tangible cultural heritage[131] to have the more significant impact on the 3D digitisation industry.

LiDAR, which stands for Light Detection and Ranging, is a remote sensing technology that uses laser light to measure distances and create precise 3D models of objects and environments. In the past, LiDAR technology was primarily used in high-end industrial applications, such as surveying and mapping, due to its high cost and complexity. However, the availability of LiDAR in high-end smartphones and tablets has broadened its usage to other areas, such as 3D production, by making it more affordable and accessible.

Photogrammetry is the process of creating 3D models using photographs, and it has traditionally been a time-consuming and expensive process that requires specialised equipment and expertise. Nonetheless, the advancement of the technology, and in particular the photogrammetry software, currently allows anyone with a camera and a computer to create 3D models.

As highlighted in the Landscape Report prepared by XR4All/XR4 Europe, the maturity of the photogrammetry technology led to a number of commercial 3D body scanners available on the market, ranging from 3D scanning booth and 3D scan cabins to body scanning rigs, body scanners with a rotating platform, and even home body scanners embedded in a mirror, all for single-person use[132.]

The popularisation of these two technologies could have a significant impact on several industries, such as virtual-worlds production, gaming, film, architecture, and product design. They could enable smaller studios and independent creators to compete with larger studios and corporations by making it easier to incorporate highly accurate and detailed 3D models in their products at a lower cost. Additionally, this could result in an increase in the quality and variety of 3D models available, as more individual could contribute to the field. This could contribute to overcoming barriers to accessing such technologies, particularly for SMEs, micro-enterprises and freelancers which make up the majority of the business landscape in the sectors mentioned above.

### *4.8.4 Positioning technology*

As indicated in the paper Research priorities for work programme 2023-2024 from the New European Media Initiative[133], although hyper-accurate positioning is key to providing highly immersive experiences in XR applications, there are still significant technological challenges related to the context of use (indoor vs outdoor) and the underlying basic technology (network-based vs vision based).

In indoor environments, UWB (Ultra-Wide Band) - based RTLS (Real Time Location System) solutions appear as an interesting alternative for precise positioning achieving accuracies of tens of centimetres. These solutions are commonly based on the deployment

[131] https://op.europa.eu/s/yzh8

[132] https://xr4europe.eu/wp-content/uploads/XR4ALL_RevisedLandscapeReport_2020_public.pdf
[133] https://nem-initiative.org/wp-content/uploads/2022/05/nem-list-of-topics-for-the-work-program-2023-2024.pdf

of a surrounding infrastructure and Time of Flight (ToF) or Time Difference of Arrival (TDOA) measurements to locate objects/people. One of the challenges of these solutions is the impact of Non-Line of Sight (NLOS) situations between the infrastructure and the locating object on accuracy. The challenge here is to develop better mechanisms, algorithms and analytical methods to enhance UWB-based RTLS, in order to improve their localisation performance in terms of accuracy, precision and robustness, especially in the z-axis. Hardware modules with multiple antennas have recently appeared in the market facilitating the implementation of Angle of Arrival (AoA) strategies. Furthermore, UWB is being progressively introduced in smartphones, with development platforms providing third party libraries for the deployment of applications, which would allow to locate people with precision without the need of additional hardware.

In outdoor environments, satellite technologies are the most common positioning technologies. The European Galileo GNSS will offer a High Accuracy Service (HAS) less than 2 decimetres which is not sufficient for most of XR applications. Thus, further research is needed to enhance the positioning accuracy. For instance, Real Time Kinematic (RTK) mechanisms allow to improve the accuracy of GNSS systems up to centimetre-level accuracy, however, this accuracy will require an excellent sky visibility and the frequent reception of correction data from an accurately located reference station.

Finally, computer-vision based systems for localisation, mostly referred as Visual Positioning Systems (VPS), such as SLAM (Simultaneous Localization and Mapping) can also provide precise positioning by using images from one or multiple cameras while constructing a map (dense or sparse point cloud) of the environment. In addition to the captured images, other kinds of data can be used to increase the accuracy of the localisation such as LiDAR and Inertial data. Despite the extended use of SLAM methods, there are still multiple challenges that need to be solved to increase the accuracy and reliability (drift, loop closure) of such algorithms. New algorithms must a) incorporate the capacity to deal with all kinds of environments (textureless, small to large-scale) including changing environments such as crowded places, places under construction, and places with evolving lighting conditions; b) must be deployable in Cloud and Edge infrastructures to provide high performance re-localisation for use-cases with critical latency issues (autonomous vehicles, augmented reality); c) must preserve privacy of the visual data collected by end-users by incorporating the anonymisation of the flows from the source; d) must be interoperable with other data types (e.g., satellite imagery, drone imagery, LiDAR) including geometry semantics.

### *4.8.5 Authoring tools*

Content creation for virtual worlds typically entails technical development (i.e., coding and development of the architecture behind a virtual experience) and graphic design components (i.e., creation of virtual avatars and design of virtual environments and objects). Thus, authoring tools for the design, editing and processing of content of virtual environments are essential for creating virtual worlds. These tools should be designed and developed for two distinct users: the expert designers and the non-expert users who only need them for updating or personalising the content of their application.

Game development engines provide developers with tools to build virtual worlds quicker and more efficiently. They simplify the handling of complex aspects like physics, sound effects, animation, network management or multi-platform compatibility.

Unity and Unreal are the most popular game engines among developers. There are other alternatives, like the open-source Godot engine or more recently, web-based engines such as Amazon Sumerian. Many gaming studios have their own engines as well (like Valve's Source).

Virtual worlds today typically offer a range of content creation tools that cater to different skill levels. For casual creators, gaming/social virtual worlds like Minecraft, RecRoom, and Roblox provide a simple user experience reusing existing elements within the game ecosystem. On the other hand, technically advanced virtual worlds like VRChat offer greater freedom and control over content creation but require the use of professional 3D software. Meanwhile, specialised tools such as Unreal Metahuman offer high-quality content creation but may have a steeper learning curve and are targeted towards skilled creators.

Several 3D content creation tools, such as Dreams, Quill, or Tiltbrush, are already available for direct use in VR. However, users must possess artistic skills to produce high-quality content using these platforms. Creator tools for AR, such as Adobe Aero, Snap Lens Studio and SparkAR, primarily focus on the creation of simple AR content or filters.

### *4.8.6 Avatars*

Avatars play a significant role in creating a sense of presence and identity for users in virtual worlds. People can customise the appearance, personality and preferences of their digital representations. Avatars allow people to express themselves in ways that may not be possible in the physical world, and they can help to create a sense of community and social connection. However, when dealing with the concept of representation of oneself in virtual worlds it brings the issue of the digital identity. When should we use a true representation of ourselves and when not? Users' representation is important as it impacts directly on how users perceive their virtual body and how they are perceived by others in the communicative experience in the virtual world.

Nowadays, many social VR experience offers an avatar creation tool. For example, VRChat, one of the most popular VR social platforms, offers an avatar editor for users to create and personalise their avatar, and many avatars system includes different skin tones, facial shapes, and some even include assistive devices, like hearing aids, wheelchairs for the avatars so users can feel better represented and included. However, despite the importance of the user representation in the feeling of presence, most of the platforms still use cartoon-like or human-like avatars. This is due to the cost and complexity to offer more realistic user representations, like those provided by real-time volumetric video capturing systems.

As virtual worlds continue to evolve, avatars are likely to become even more sophisticated and customisable. They may also become an important part of commerce and marketing, with companies creating branded avatars to interact with customers and promote their products and services. This represents opportunities for the fashion industry, among others.

There is still work to be done to create a visual identity interoperable through different virtual worlds, and especially to create a true digital identity shared among all the applications in virtual worlds.

### *4.8.7 Human-Computer Interfaces (HCIs)*

In the context of virtual worlds, human-computer interfaces (HCIs) will be critical in enabling users to fully engage with and navigate virtual environments. The development of HCIs has advanced significantly in recent years, and there are now a wide variety of devices and technologies providing XR users with more immersive and natural ways of interacting in virtual environments. These HCIs include both the devices (such as VR headsets, smart/AR glasses and haptic wearables), and natural interfaces (such as voice, gesture and gaze). It is likely that HCIs will continue to play an increasingly important role in the development of virtual worlds as they become more integrated with our daily lives. These interfaces will enable us to interact with and manipulate digital objects and environments in ways that are currently not possible, blurring the lines between the physical and virtual worlds.

A typical hardware setup for using XR content includes a headset or head-mounted display (equipped with handles or controllers to navigate the digital world in the case of VR). Most headsets are produced outside of Europe, with five particularly strong market players in terms of production volumes: Microsoft (US, specialised in AR and MR); Meta (US, which bought in 2014 one of the pioneering companies in VR, Oculus); HTC (Taiwan, one of the early developers of VR headsets in collaboration with Valve); Sony (Japan, mostly involved in videogame applications with its PlayStation VR) and ByteDance (Chinese, bought Pico VR in 2021). European companies are also in the headset game, with Varjo (Finland) and Lynx (France) being examples of European-produced XR hardware.


*Figure **Error! No sequence specified.**14. Map of European device manufacturers. Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[134]

Although hardware components and architectures for XR devices have achieved tremendous progress in the last years, many technical limitations remain to be solved before these devices are fully ready for widespread use. Out of the multiple XR hardware components, optical systems and displays are probably the elements where the state-of-the-art technology still faces the most challenging limitations. Understanding the specifics of human perception and physiology, following a human-centric optical design process, is critical for engineering XR systems.

[134] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education

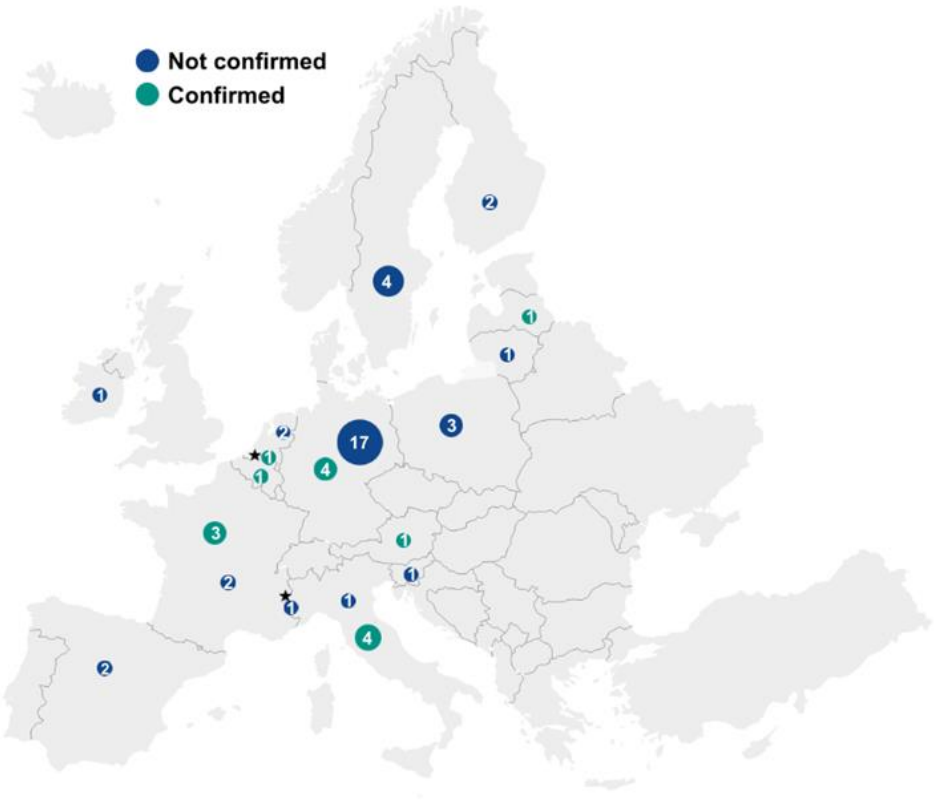


*Figure 13. Map of component manufacturers in Europe.Source: Visionary Analytics – Survey Extended Reality: Opportunities, Success Stories and Challenges (Health, Education)*[135]

Multiple optical parameters, such as field of view, eye box, eye relief, resolution, brightness, transparency and contrast, influence the devices' display technology and determine the performance of the system. Despite the efforts of researchers, engineers and manufacturers, most of these parameters are not yet at an optimal level. Moreover, because all these parameters are directly interrelated, improving one of them without sacrificing others is a complex engineering challenge.

Technological breakthroughs in photonics, along with the use of new materials such as photopolymers or metamaterials in optical components, will increase image quality and reduce the size and weight of hardware components, leading to a new generation of XR devices with a much more compact form factor. Better optical architectures will bring XR devices' capabilities closer to the human eye's optical properties of resolution, colour sensitivity and uniformity over large FOVs, self-adaption to focus location, brightness and contrast. These architectures will boost the efficiency of XR components for enhanced performance, reduced power consumption and improved heat dissipation. Novel XR display systems will cater to the widest range of users, including those that need prescription correction.

By providing greater visual, wearable, vestibular and social comfort, the new generation of XR devices will allow for richer and more immersive experiences.

[135] Survey on Extended reality: opportunities, success stories and challenges in health and education https://digital-strategy.ec.europa.eu/en/library/extended-reality-opportunities-success-stories-and-challenges-health-and-education

As mentioned in the Research Agenda[136] drafted by XR4All/XR4Europe future XR applications require ubiquitous sensing of and feedback to the user. The user should be able to feel, touch and interact with the virtual world in a truly immersive manner. This also includes the removal of controllers and to allow for a realistic interaction purely with its hands, body posture, eyes, speech etc. Haptic technology simulates touch and manipulation of virtual objects through tactile feedback using wearable devices such as gloves, vests, controllers, and actuators. Haptic technology enhances the sensory experience in XR applications, making them more immersive and engaging. As XR technologies advance, haptic technology will play a crucial role in creating truly immersive virtual experiences.

According to EuroXR[137], the EU is at the forefront of scientific research in haptic technologies, with prestigious research teams in the field in Munich, Pisa, Paris, Grenoble and Delft, as well as important conferences such EuroHaptics and ACTUATOR. EU haptic technology is also relatively present in the professional market, with OEMs such as Valeo, Bosch and Continental in the providing haptic solutions for the automotive sector and two manufacturers of generic force-feedback devices, Haption in France and MOOG in the Netherlands. Although advancements have been made in recent years, certain scientific and technological challenges still require significant progress. These challenges include the development of more efficient actuation technology, the enhancement of energy efficiency in haptic systems, and the improvement of accuracy in physics simulations. Technological breakthroughs in these areas are necessary to further improve haptic technologies and enable their widespread use in various industries.

Finally, natural interfaces, strongly rely on the use of Artificial Intelligence technology.

## 4.9 Artificial Intelligence

### *4.9.1 Machine learning, Deep Learning and Generative AI.*

Currently, virtual worlds combine artificial intelligence (AI) with technologies such as computer vision and networking to create secure, scalable, and realistic virtual environments on a reliable, always-on platform. AI plays an essential role in ensuring infrastructure reliability and improving performance. Advanced machine learning (ML) algorithms are employed in 5G networks for various tasks, including spectrum monitoring, resource allocation, and network fault detection.

In the current state of the art, computer vision, powered by AI, especially deep learning (DL), has improved the accuracy and efficiency of visual systems. Fundamental computer vision technologies have the potential to enhance user experiences in virtual worlds, enabling seamless interactions between the physical world and the virtual environment. AI-powered ML and DL models can analyse and recognise simple and complex human movements, projecting users' actions into virtual worlds and enabling them to control their avatars comfortably.

[136] https://xr4europe.eu/wp-content/uploads/XR4ALL_FinalResearchAgenda_2020_public.pdf
[137] Roadmapping XR: Fundamentals and Applications, 2022. (eds.) Alcaniz, M, Sacco, M., Tromp, J. G., Wiley-Scrivener, USA, ISBN-13: 978-1119865148

One of the trends in the coming years is the use of generative AI models. Generative AI, based on foundation models, is a recently developed technology capable of generating new and unique content for various applications. These models are created by training a foundation model on large amounts of data and then fine-tuning it on a specific task.

Although most generative AI models have focused on text generation, exploring additional modalities beyond text presents a new avenue for extending AI systems' capabilities. By incorporating diverse modalities, generative AI will be able to autonomously create new content, such as landscapes, characters, and objects, based on predefined rules and parameters. This will contribute to the richness and diversity of virtual worlds while also reducing the time and effort required to develop them.

Generative AI will play a crucial role in creating 3D objects for virtual worlds, enabling the seamless synthesis of intricate and realistic virtual environments. Text-to-3D synthesis will allow users to generate 3D models simply by describing their desired objects or scenes in text form. This innovative approach will empower even novice users to create complex and detailed 3D assets with ease. Similarly, sketch-to-3D model conversion will enable users to transform 2D sketches into realistic 3D representations using generative artificial intelligence. By leveraging these advanced technologies, users will be able to effortlessly bring their creative visions to life, enriching the virtual worlds with unique and diverse content.

Several European companies are actively leveraging artificial intelligence, contributing to the development of virtual worlds, and enhancing user experiences. Notable examples include NeosVR, a Czech company offering a social VR platform with AI-enhanced user-generated content; Artomatix, an Irish startup specialising in AI-driven 3D content creation tools; and Quixel, a Swedish company providing high-quality 3D assets and AI-optimised tools for virtual world development.

### *4.9.2 Language Technologies and Natural Language*

Language technologies, also called Natural Language Processing (NLP), can play a crucial role in the development of the virtual worlds, supporting a more engaging, immersive, and inclusive experience. By enhancing communication and interaction between users and with the virtual environment, NLP technology can bring virtual worlds closer to the level of sophistication and nuance of the real world in different ways:

- Language technologies can play a key role in enabling speech-based communication within virtual worlds, by enabling chatbots and virtual assistants to understand the meaning of spoken words and respond appropriately with appropriate intonation, pacing, and emphasis.
- Language analytics can be used to analyse the communications and improve the virtual environment in several ways from personalising the user experience to addressing negative interactions and support automatic content moderation by providing immediate help to users.
- Machine translation technology, providing automatic translation of text messages, voice communications, or even live conversations between users in different languages, can make it easier for people from different parts of the world to communicate and collaborate in virtual environments. This will support a more

inclusive and global community within the virtual world and ensure the respect of linguistic diversity[138].

- One of the main trends in the NLP sector is the development and deployment of Large Language Models (LLMs). Typically consisting of billions of parameters, LLMs are pretrained on a very large amount of data to learn patterns and rules of natural languages and can be used in many applications such as machine translation, question answering or text generation, with little or no fine-tuning. Their potential to virtual worlds is vast. In particular, emerging trends such as multimodality and conversational AI powered by LLMs could bring interaction in virtual worlds even further. Multimodal language models will be able to interpret gestures, body language and non-verbal cues for enhanced communication, while more and more human-like assistants will make human-to-machine interaction virtually seamless, in written or spoken mode.

This domain is evolving quickly, and challenges such as data copyright and GDPR compliance require continuous monitoring especially concerning the data collection practices required to build such large language models beyond the research domain, as well as the effective exercise of data subject's rights.

Beyond research endeavours such as the BLOOM model by Open Sciences[139], OpenGPT-X in Germany[140] or GPTSW3[141] in Sweden, European players such as Aleph-Alpha and its Luminous models[142] or LightOn[143] start providing commercial solutions.

### *4.9.3 AI agents and virtual beings*

In virtual worlds not all the avatars will be human controlled, there will be also avatars controlled by artificial intelligence know as AI agents or non-playable characters (NPCs) (designed primarily to perform tasks in various industries) and virtual beings (designed for entertainment or social purposes).

An important role for AI agents in virtual worlds will be to help manage and monitor the virtual environment. As virtual worlds grow in size and complexity, it will become increasingly difficult for human moderators to keep track of everything. Virtual beings could help users navigate the virtual world, locate specific content or other users, and provide context-aware recommendations based on a user's interests and behaviour. They could also assist with tasks such as shopping, booking reservations, etc. In addition, AI technologies can play a crucial role in combating misleading content and disinformation in virtual worlds. There are already several tools and techniques developed to detect and counter the spread of false information, for example the NLPs, fact-checking algorithms, image and video analysis, social network analysis, sentiment analysis, bots and fake avatar detection, specific content recommendation systems, etc. In the future, AI agents could be

[138] Article 22 of the Charter of Fundamental Rights of the European Union (2000/C 364/01)
[139] https://bigscience.huggingface.co/blog/bloom
[140] https://opengpt-x.de/en/
[141] https://www.ai.se/en/news/pre-release-gpt-sw3
[142] https://www.aleph-alpha.com/
[143] https://www.lighton.ai/fr

programmed to identify and flag inappropriate behaviour or content, enforce rules and regulations, and even provide automated mediation in cases of disputes in virtual worlds.

There is a clear evolution from voice-only digital assistants (e.g., Siri, Cortana, Alexa, Google Assistant, Bixby, etc.) and text-based chatbots into virtual assistants that can provide a more immersive 3D interaction. Virtual beings are estimated to become an extremely profitable market, yet its maturity is still on an early stage and open to research.

As indicated by EuroXR in its State of XR report 2021[144], advancing in the development of virtual beings will require research in:

- Avatars realism technologies, to make the appearance of a virtual being similar to a physical person, avoiding the "uncanny valley" effect.
- AI and Machine Learning (ML) so that the virtual being is able not only to speak naturally with people, but also to remember the history with every other real or digital person and behave with that person accordingly.
- AI and ML so that a virtual being understands the context inside which they are in, therefore triggering specific actions (e.g., helping the user).
- Behavioural studies and expression, so that virtual beings understand and adapt their behaviour according to the context, throughout all their means of expression, being words and other kind of body language.
- Ethical studies and legal implications (e.g., reliving a dead person in VR, or what are the consequences of harassing a virtual being), making sure we build a sustainable and ethical future also inside virtual worlds.

### 4.10 Electronics and photonics

Nowadays, chipmakers are miniaturising their technology and processes as much as possible aiming at faster and more energy-efficient processors. These next generation chips can give devices longer battery life and help reduce the energy consumed by data centres. State of the art power management chips will be essential to reduce power consumption of mobile devices. Flexible electronics will contribute to use haptic experiences in virtual worlds[145]. Furthermore, semiconductors help on making devices smaller and more ergonomic. These technological developments are important for improving the user experience of virtual worlds in its full potential.

In addition, photonics technologies combined with microelectronics are steadily evolving AR/VR technology to be smaller, lighter, and less power-hungry, as well as more immersive and intuitive for end users. Innovative Photonic technologies enabled projectors, displays, waveguides and cameras and have continuously improved the performance and power consumption of AR/VR headsets[146]. In the future, brighter light sources, more efficient delivery optics, and better eye-tracking will be needed.

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[144] Roadmapping XR: Fundamentals and Applications, 2022. (eds.) Alcaniz, M, Sacco, M., Tromp, J. G., Wiley-Scrivener, USA, ISBN-13: 978-1119865148

[145] Functional Materials and Devices for VR/AR Applications in Advanced Functional Materials: Vol 31, No 39 (wiley.com) - 2021

[146] Photonics Shapes the Worlds of Augmented and Virtual Reality, https://www.photonics.com/Issues/Photonics_Spectra_August_2021/i1280

One example is the design of high-performance AR/VR glasses/headsets. To simultaneously match the exceptional performance of human vision and keep the near-eye display module compact and lightweight imposes unprecedented challenges on optical photonic engineering[147]. Recent progress in holographic optical elements (HOEs) and lithography-enabled devices have enabled innovative ways to tackle these obstacles in AR and VR that are otherwise difficult with traditional optics.

Improvements in display and optics design and development are currently enhancing AR/VR systems and providing novel opportunities for applications and market growth. Sample trends in AR/VR applications include

- novel display and AR technologies assisting drivers and creating new interior environments in private and public transportation,
- augmented-reality surgery visors e.g., superimposing data and x-ray images onto the surgeon's field of vision, raising the efficiency and precision of the surgery process,
- visual communications such as AR and 3D display technologies transforming manufacturing processes, from product design to production to maintenance.

Europe is a key player in this process, and European photonics companies are poised to participate in shaping this development. Enterprises engaged in photonics technology and market development include Aledia (France), Bosch Sensortec (Germany), Carl Zeiss (Germany), Dispelix (Finland), Imagine Optic (France), Lynx Mixed Reality (France), MICROOLED (France), Morphotonics (Netherlands), NKT Photonics (Denmark), STMicroeletronics (Switzerland, France, Italy) and TriLite Technologies (Austria) and others 2021).

As the market demands further miniaturization and energy-efficient solutions for all AR/VR applications, further advances for high resolution and high brightness micro-displays are needed. While there are several European companies developing solutions for micro-displays, among the major challenges is to participate in defining what will be the standard in the future. Existing state-of-the-art technology include LCDs and digital light projectors; emerging solutions embrace micro-displays based on LED and OLED technology as well as liquid crystal on silicon and novel compact laser beam scanning based light engines.

Required research and development work also includes optical components such as micro- and freeform optics to save space and make headsets more comfortable with large fields of view.

A further research focus is on diffractive waveguides for replacing conventional optics thereby considerably reducing installation space, doubling the field of vision with the ability to project images directly into wearers' eyes and on enhanced solution for eye tracking. Work on multimodal multi-sensor systems and information fusion is also required, particularly in industrial applications.

[147] Augmented reality and virtual reality displays: emerging technologies and future perspectives | Light: Science & Applications (nature.com) 2021

## 4.11 Internet of Things

IoT is a prime example of a technology bridging the physical and virtual worlds – allowing to analyse data from the physical environment using sensors, to glean insights and take appropriate action. This could be anything from a homeowner monitoring the energy generated by a solar panel, the efficiency of heating or cooling, to a manufacturer monitoring asset performance and predicting breakdowns or repairs. IoT potentially enables to connect the virtual world with the physical world. Connecting the digital senses of an environment is the essence of IoT.

By connecting devices and sensors to the internet and using data analytics to derive insights and make intelligent decisions, virtual-world experiences can be more engaging and immersive. For example, IoT sensors can be used to track a user's biometrics and adjust the virtual environment accordingly, and IoT data can feed realistic simulations of processes in industrial virtual worlds. With AI assistants in glasses and other smart devices, Ambient Intelligence can help create personalised and responsive environments that adapt to the preferences and behaviour of the user in real-time making them more comfortable and intuitive.

Especially for industrial virtual worlds, IoT will play a critical role in building various blocks, by creating an interoperable, seamless system of systems, and integrating digital content into a physical environment. Practically, this could be essential for combining digital twins and immersive experiences to generate real-time feedback control for complex assets such as machines and/or energy flows or processes in the physical world. Integrating Digital Twins with IoT will allow to access, visualise and analyse equipment performance data – allowing to group sensors and their data in near real-time, and connect the 'real' and 'virtual' worlds more meaningfully and intuitively for the operator or user.

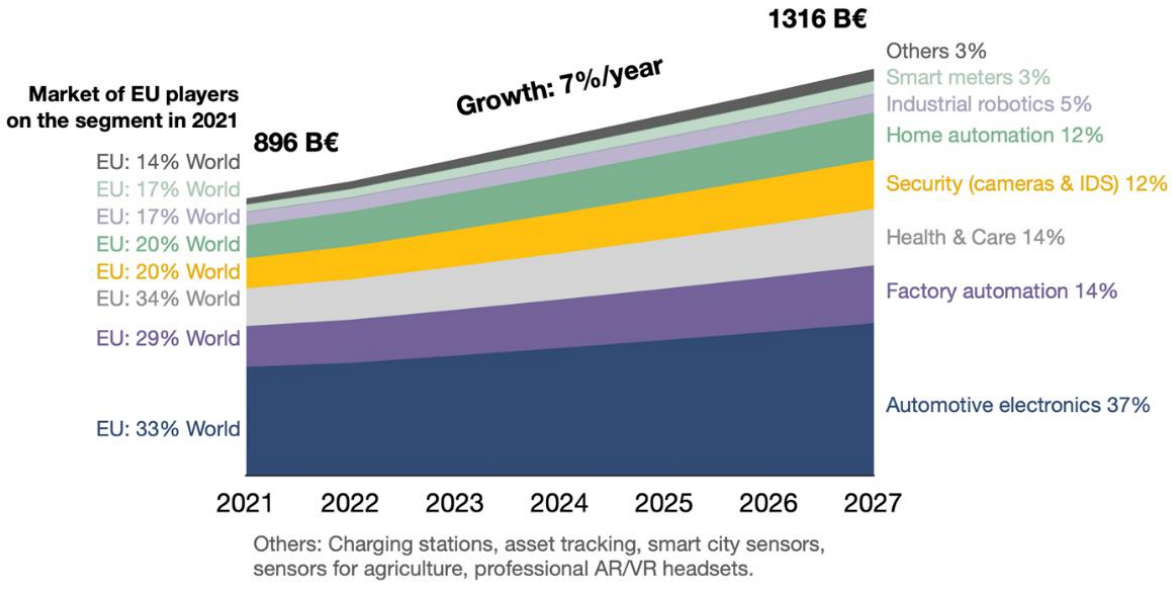


*Figure 14. Global Professional IoT market: Forecasts 2021-2027. Source: DECISION Etudes & Conseil*

According to Markets and Markets, the global IoT Market size in terms of revenue is estimated at EUR 300 billion in 2021 and is anticipated to rise to EUR 650 billion by 2026, presenting a CAGR of 16.7%. Major drivers fuelling the IoT market include access to low-cost, low-power sensor and network technology, availability of high-speed connectivity, increase in cloud adoption and increasing use of data processing and analytics, especially at the edge.

The IoT market is expanding rapidly across many "industrial" applications, including smart agriculture, industry 4.0, smart building, mobility, manufacturing etc. According to DECISION Etudes & Conseil, it is expected that there will be 11 billion professional IoT devices deployed by 2027. A direct consequence of IoT and the devices and applications it powers, is the unprecedented amount of constantly changing data that is generated as a result. This data needs to be processed in close to real-time if meaningful conclusions are to be drawn and swift decisions made to avoid bottlenecks and keep operations up in industrial processes as delays can have major repercussions for physical processes, operational efficiencies or cost effectiveness. According to IDC Data Age report, the importance of real-time in global datasphere will increase up to 30% by 2025. Real-time and low latency are prerequisite for industrial virtual worlds.

- Source: IDC Data Age 2025, Nov. 2018

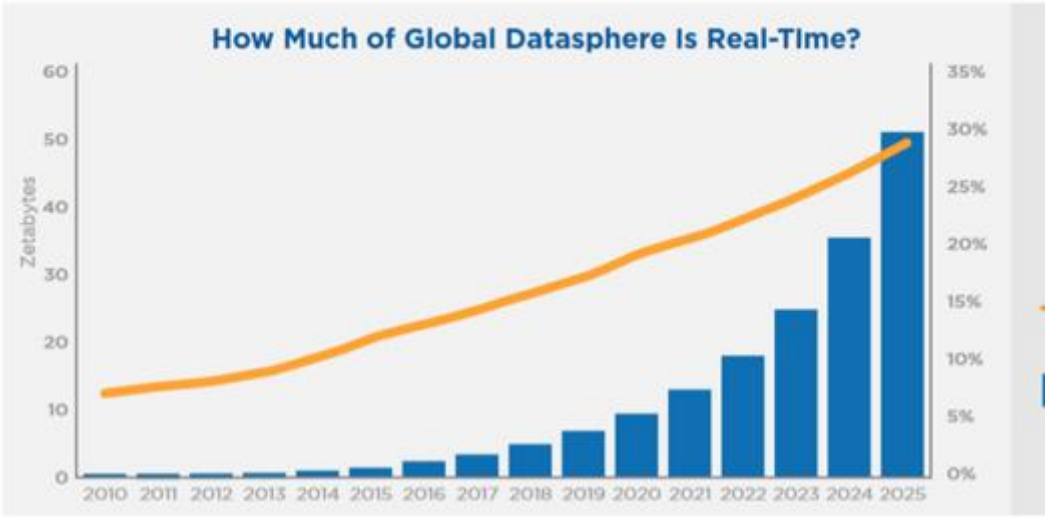


*Figure 15. Source: IDC Data Age 2025, Nov 2018*

As far as the EU's position in production is concerned, 20% of the production of Industrial IoTs is located on the EU territory. Edge computing is a way to increase the semiconductor fabrication capabilities in Europe, by creating more value at the edge devices and reducing the impact of competitiveness. The opportunity for Europe is at the intersection of the Cloud IT world (or virtual worlds in the cloud) and the operational world, because Europe is strong in terms of system design, production and electronic control systems. One of the next innovation waves is through industrial virtual worlds, with a focus on B2B platforms and edge disruptive technologies for industrial and business. The industrial virtual worlds will be at the heart of digitisation across key sectors like automotive, manufacturing, energy, agri-food, healthcare, building and logistics.

## 4.12 Artificial Intelligence of Things

The Artificial Intelligence of Things (AIoT) is expected to play a major role in truly immersive experience and ambient intelligence. AIoT is the combination of Artificial intelligence technologies with the Internet of things infrastructure to achieve more efficient IoT. AIoT is usually implemented running the AI on the device, also known as Edge AI. Edge AI is an emerging paradigm that combines AI and edge computing, shifting the processing and decision-making capabilities closer to the data source.

Until recently, AI computations have almost all been performed remotely in data centers, on enterprise core appliances, not locally on devices. This is because AI computations are extremely processor-intensive, requiring hundreds of (traditional) chips of varying types to execute. Now, edge AI chips are changing all that. They are physically smaller, relatively inexpensive, use much less power, and generate much less heat, making it possible to integrate them into handheld devices such as smartphones as well as industrial IoT devices. By enabling these devices to perform processor-intensive AI computations locally, edge AI chips reduce or eliminate the need to send large amounts of data to a remote location—thereby delivering benefits in usability, speed, and data security and privacy.

The industrial virtual worlds are expected to be powered by AI embedded at the edge. According to Deloitte, they predict that in 2020, more than 750 million edge AI chips—chips or parts of chips that perform or accelerate machine learning tasks on-device, rather than in a remote data center—will be sold, representing a USD 2.6 billion in revenue, Further, Deloitte predicts that the edge AI chip market will continue to grow much more quickly than the overall chip market. By 2024, we expect sales of edge AI chips to exceed 1.5 billion, possibly by a great deal. This represents annual unit sales growth of at least 20 percent.

This approach to decentralised computing enables real-time analysis and decision-making directly on the devices and sensors that generate the data, creating multiple advantages. Because information is not sent to remote servers, Edge AI reduces the risk of data breaches and thus enhances privacy and security. It is also easier to scale the resulting Ambient intelligence systems because edge computing can maintain performance and responsiveness even when the number of IoT sensors and devices increases.

Europe is not leading in AI chips – it is rather big IT companies like Intel and Google, for instance, which are currently selling internally developed standalone edge AI chips to developers. Nvidia, the leading manufacturer of graphics processing units (GPUs) commonly used in accelerating data center AI—which are very large, use hundreds of watts of electricity, and can cost thousands of dollars—now sells a customised AI-specific chip (that is not a GPU) suitable for edge devices that is smaller, cheaper, and less power-hungry. Qualcomm, the leading maker of merchant market SoCs with embedded edge AI processing cores for smartphones and other consumer devices, has released two standalone edge AI chips that are less powerful than its SoCs, but that are cheaper, smaller, and use

less electricity. Also, Chinese suppliers like Huawei are investing heavily while European players like ST Micro and Bosch are slowly catching up.

dAIEDGE, a Network of Excellence in AI, will bolster the advancement of edge AI technologies and applications in Europe. The Networks of Excellence in AI are a European Union initiative that bring together leading research teams from across the continent to tackle pressing scientific and technological challenges in the field of artificial intelligence.

### 4.13 Digital identity

In the context of virtual worlds, digital identity becomes important for ensuring security, privacy, and trust in online interactions. It will also play a crucial role in serving as the primary means of identifying and authenticating individuals in those virtual environments. A person's digital identity in virtual worlds may include their avatar, their personal information and their digital credentials.

With the Regulation (EU) N°910/2014 on electronic identification and trust services for electronic transactions in the internal market the EU (eIDAS Regulation)[148] the EU established a first of a kind interoperability framework and a trust model aimed to creating collective cross-border confidence in the security of national electronic identity schemes. The vision was to build a network to connect electronic identity schemes created at national level and to empower citizens to access public services cross-border.

However, taking stock of progress in 2021 it became clear that the EU needs to go a step further and improve Digital Identity. The system was slow to establish - 8 years since adoption, 16 Member States notified had an electronic identification scheme - and more than a quarter of the of EU-27 population had no access. In addition, in practice, the current system works only for public sector applications, there is low uptake by the citizens and in many Member States few services are connected. and certain electronic identity solutions are not user-friendly enough (no common user interface, redirections in the authentication process and denial of service). Most importantly, the public sector is only a small fraction of the internet use.

The European Commission has therefore proposed a revision of the Regulation that facilitates large-scale deployment of a user-controlled trusted digital identity enabling every citizen to master their online interactions and to monitor the use of their personal data. It will help meeting the ambitious target set by the Digital Decade of Europe is, to ensure that by 2030, all European citizens have access to a digital identity.

The Commission’s proposal will bring together the possibility to securely authenticate for accessing public and private online services (e.g., enrolling for university, conducting financial transactions or renting a car) with the opportunity to share attested information about oneself (e.g., one’s diplomas, driving license or credit rating). This will allow users to conduct transactions fully online

[148] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0910

The proposal demands a user centric design so that users can exercise control over their identity and online data and allowing access to digital services. It defines the conditions for establishing European Digital Identity Wallets to be issued by all Member States while ensuring the highest possible level of security.

Building on common standards, to be defined together with Member States, the cross-border functioning of the Wallet will be built in by default. By mandating very large platforms, as well as private companies that require strong user authentication, to accept the use of the European Digital Identity Wallet as a means to authenticate, it will give users access to a vast range of private online services in addition to public services.

By introducing a new trust service for the electronic attestation of attributes, such as university diplomas, professional titles, public permits and licenses, and financial and company data, for example, the proposal creates new business opportunities.

On 3 June 2021, the Commission adopted a Recommendation calling on Member States to work towards the development of a Toolbox including a technical Architecture and Reference Framework (ARF)[149], a set of common standards and technical specifications and a set of common guidelines and best practice. Cooperation started in parallel and in full respect of the legislative process and in alignment with its outcome.

Virtual worlds, for technical as well as business reasons, are likely to be access controlled, so identity management will be an integral part of the technology. A strong EU digital identity framework will help protect users against identity fraud, enforce accountability for behaviour in virtual words and in this way facilitate the social, business, and legal aspects arising from the area.

As it is already evident in online games, users are also likely to acquire attributes (ownership of virtual objects, skills etc.) when acting in virtual words, attributes they may want to protect, proof or transfer across systems. It will have to be explored what contribution electronic attestations of attributes, as understood by the European Digital Identity Framework can make in this context.

### 4.14 Standards

Standard sets of protocols and interfaces are essential to allow seamless interoperability between different platforms and technologies. This is where standardization comes into play.

In a Web 4.0 that lacks standardization, different platforms might use different file formats, data structures, communication protocols, and security mechanisms, making it difficult or impossible for users to move between different virtual worlds and services or for developers to create cross-platform tools and applications (which would lead to reducing development costs and increasing the potential user base).

By implementing appropriate data/cybersecurity measures that are consistent across platforms and applications, and reducing the risk of hacks or data breaches, standards are

[149] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_2663

essential to create safe and trustworthy virtual worlds and Web 4.0. Moreover, open standards will help prevent fragmentation and user lock-in into proprietary platforms.

Some of the most relevant ICT standard development organizations (SDOs), such as IEC, IEEE, ISO/IEC, ITU and, W3C have already engaged in pre-standardization activities for virtual worlds. In parallel, other non-SDO initiatives, such as the Metaverse Standards Forum, Khronos Group and Open AR Cloud are fostering the creation and evolution of virtual worlds and Web 4.0 related standards within standards organizations. These initiatives are focused among other on promoting safety, security, ethics, and interoperability in immersive environments, and aim to ensure that virtual identities, digital assets, and services are highly interoperable and transparent across platforms.

### *4.14.1 Standards Developing Organizations (SDOs)*

**ISO/IEC** (International Organization for Standardization / International Electrotechnical Commission) ISO/IEC JTC 1/SC 24[150] has published standards relevant to 3D virtual world representation, visualization, and information processing; 3D avatar representation, visualization, and information processing; and VR/AR/MR-based information processing with 3D virtual worlds and avatars. In addition, ISO/IEC JTC 1/SC 29[151] contains the well-known JPEG and MPEG standardization groups for interoperable and efficient coded media. These technologies are fundamental to virtual worlds and XR development.

**IEC** (International Electrotechnical Commission) IEC/TC 100 develops international standards in the field of audio, video and multimedia systems and equipment (colour measurement and management, digital system interfaces and protocols, wearable electronic devices and technologies and applications for end-user networks). Recently, it has established a Working Group on multimedia systems and equipment for metaverse[152].

**IEEE** (Institute of Electrical and Electronics Engineers) has established the IEEE Metaverse Congress series[153] and the Metaverse Community. IEEE also has pre-standardization activities such as the Global Initiative on ethics of XR[154], in which the note Metaverse and its governance[155] has been developed.

**ITU** (International Telecommunication Union) Telecommunication Standardization Sector (ITU-T) started specific metaverse activities within Study Groups SG16, SG17 and SG20, such as for example the October 2022 workshop on metaverse and multimedia[156]. Moreover ITU-T Telecommunication Standardization Advisory Group (TSAG) established in December 2022 a new Focus Group on metaverse (FG-MV)[157] to carry out pre-standardization work with specific terms of reference.

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[150] https://www.iso.org/committee/45252.html
[151] https://www.iso.org/committee/45316.html
[152] https://www.iec.ch/dyn/www/f?p=103:14:8804596874983:::FSP_ORG_ID,FSP_LANG_ID:42313,25
[153] https://engagestandards.ieee.org/IEEE-Metaverse-Congress.html
[154] https://standards.ieee.org/industry-connections/ethics-extended-reality/
[155] https://standards.ieee.org/wp-content/uploads/2022/06/XR_Metaverse_Governance.pdf
[156] https://www.itu.int/en/ITU-T/Workshops-and-Seminars/2022/1018/Pages/default.aspx
[157] https://www.itu.int/en/ITU-T/focusgroups/mv

In February 2022, **3GPP** (3rd Generation Partnership Project) established the Local Metaverse Study Item to analyse the requirements for providing timely media to multiple users with sufficiently low latency and synchronization to enable services based on rapid interaction with virtual objects, localised interactive XR media and spatial information.

**W3C** (World Wide Web Consortium) is an international community that develops open standards for the Web. In April 2021, W3C established the Metaverse Interoperability Community Group (MICG)[158] to bridge virtual worlds by designing and promoting protocols for identity, social graphs, inventory, and more. MICG wants to bolster the metaverse as an open and interoperable resource for anyone, inspired by the collaborative efforts of the community. Currently, there is no official scope of this group but it is interested in the digital identity, virtual world URIs, avatar and digital asset portability, etc.

The Web3D Consortium[159] promotes deployment of X3D (ISO/IEC Standard) for the communication of interactive 3D scenes in multiple applications, use cases, platforms, and verticals. Members collaboratively develop the X3D standards and tools making them widely adopted across diverse markets for academia, government, industry, and individuals. X3D Version 4 aims to provide for the interoperability between interactive 3D worlds to enable an open, unified Metaverse.

The XR Safety Initiative (XRSI)[160] is a global non-profit Standards Developing Organization that promotes privacy, safety, security, and ethics in immersive environments.

### *4.14.2 Other, non-SDOs, initiatives*

The Metaverse Standards Forum[161] is an umbrella organisation which does not create standards itself but coordinates requirements and resources to foster the creation and evolution of Metaverse related standards within standards organizations such as Khronos Group, W3C, Open Geospatial Consortium, OpenAR Cloud, and Spatial Web Foundation, among other. It counts already with more than 1500 members, including Meta, Microsoft and Google.

The Khronos Group[162] is an open, non-profit, member-driven consortium of 170 organizations developing, publishing and maintaining royalty-free interoperability standards for 3D graphics, VR, AR, parallel computation, vision acceleration and machine learning. Some of the more widely adopted specifications are OpenGL[163] (a cross-platform 2D/3D graphics API), glTF [164](standard file format for 3D scenes and models) an OpenXR[165] (a royalty-free, open standard for XR platforms and devices). The group's more relevant members include Apple, Google, Intel, NVIDIA, Qualcomm, Samsung and Sony.

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[158] https://www.w3.org/community/metaverse-interop/
[159] https://www.web3d.org/
[160] https://xrsi.org/
[161] https://metaverse-standards.org/
[162] https://www.khronos.org/
[163] https://www.khronos.org/opengl/
[164] https://www.khronos.org/gltf/
[165] https://www.khronos.org/openxr/

The Open Metaverse Alliance for Web3 (OMA3)[166] is a collaboration of Web3 metaverse platform creators (The Sandbox, Animoca Brands, Decentraland, etc) to ensure virtual land, digital assets, ideas, and services are highly interoperable between platforms and transparent to all communities.

The Open AR Cloud[167] aims to drive the development of open and interoperable AR Cloud technology, data and standards to connect the physical and digital worlds.

Under the umbrella of the Linux foundation, the Overture Maps Foundation[168] is a collaborative effort to develop interoperable open map data to power mapping and location services worldwide. It is open to companies of all sizes with a common interest in open map data. Founding members are Amazon, Meta, Microsoft and Tomtom.

The Open Geospatial Consortium (OGC)[169] is a worldwide community committed to improving access to geospatial, or location information. It creates free, publicly available geospatial standards that enable new technologies. OGC also manages a R&D Innovation Program.

The Spatial Web Foundation[170], aims to develop and maintain the technical and ethical standards of the Spatial Web such as spatial domains, Hyperspatial Language (HSML), a universal spatial protocol standard (HSTP), and distributed ledger for identity and value (Statefulness).

The Enosema Foundation[171] develops international standards for managing concepts and their usage across organizations. Enosema joined the Metaverse Standards Forum as a Principal and founding member to enable semantic interoperability in the metaverse.

Universal Scene Description (USD)[172] is an open and extensible protocol for describing, composing, simulating, and collaborating within 3D worlds, originally invented by Pixar Animation Studios. Companies such as Nvidia are pushing USD) as the "HTML of the metaverse"[173].

The VRM Consortium[174] was established to advocate for the platform-independent 3D avatar file format VRM[175], to disseminate VRM, and to establish unified standards.

The Open Metaverse Interoperability Group (OMIGroup) [176]is an open-source community of industry professionals, independent creators, and enthusiasts building open interoperable technology for virtual worlds (eg. interoperable identity, social graphs, inventory, etc.).

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[166] https://www.oma3.org/
[167] https://www.openarcloud.org/
[168] https://overturemaps.org/
[169] https://www.ogc.org/
[170] https://spatialwebfoundation.org/
[171] https://www.enosema.org/
[172] https://graphics.pixar.com/usd/
[173] https://developer.nvidia.com/blog/universal-scene-description-as-the-language-of-the-metaverse/
[174] https://vrm-consortium.org/en/
[175] https://vrm-consortium.org/en/#vrm
[176] https://omigroup.org/

The Immersive Digital Experiences Alliance (IDEA)[177] is a non-profit industry alliance working towards developing a family of royalty-free technical specifications that define interoperable interfaces and exchange formats to support the end-to-end conveyance of immersive volumetric and/or light field media.

The Volumetric Format association[178] is a non-profit trade association of technology providers that believe volumetric video is the next revolution for content creation and distribution. Microsoft, Zeiss, Sony, NVIDIA, Intel and Verizon are among the association's members.

### *4.14.3 European Standardisation Organisations (ESOs)*

Although for the time being European Standardisation Organisations are not carrying out specific activities regarding virtual worlds and Web 4.0, it is worth to mention that ETSI (European Telecommunication Standards Institute) Industrial Specification Group for Permissioned Distributed Ledgers (ISG PDL)[179] includes a proof of concept dealing with the metaverse (PoC 03: Timeless in Metaverse Environment based on Edge networks).

Furthermore, CEN (European Committee for Standardization) with the participation of the Horizon 2020 ARETE project, has produced a draft CEN Workshop Agreement (CWA)[180] which includes a comprehensive canon of standards for the creation, delivery, and use of extended reality learning activities and 3D augmented reality objects for intensive educational processes.

## 4.15 Integration and engineering of new platforms and systems for virtual worlds and Web 4.0

Integrating all the technologies presented in the previous sections into advanced virtual worlds platforms and Web 4.0 systems is a complex task that poses significant challenges. If not properly planned for and addressed, these challenges could lead to compatibility issues that result in inefficiencies, operational disruptions or security vulnerabilities. To ensure that the different technology components work together seamlessly, the following key aspects must be addressed.

Truly integrated virtual worlds, platforms and web 4.0 applications will be those that communicate and share data effectively and are compatible with each other and with existing protocols and data formats. Two examples of the benefits of such interoperable integration are cross-platform compatibility, which will allow virtual worlds to be accessed and used across different devices and platforms; and accessibility, which will enable the integration of assistive technologies (such as screen readers) into virtual worlds and Web 4.0 solutions. SMEs will also benefit of interoperability as it will ensure the existence of multiple providers, limiting monopolies.

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[177] https://www.immersivealliance.org/
[178] https://volumetricformat.org/
[179] https://www.etsi.org/committee/1467-pdl?jjj=1657002702200
[180] https://www.cencenelec.eu/media/CEN-CENELEC/News/Workshops/2023/2023-02-21%20-%20XR/draftcwaxrlpa_publiccommenting.pdf

By devising scalable and modular solutions, developers and technology providers will ensure that as virtual worlds and Web 4.0 solutions evolve, they continue to deliver seamless user experiences[181]. Scalability will allow these systems to adapt to changing needs, handle ever-increasing user bases and data traffic, store and manage large data sets, enabling smooth data processing and retrieval, especially as they will need to support a big number of concurrent users and applications. Modularity will help manage complexity by making it easier to swap components or add new ones, without slowing down or disrupting existing systems and processes.

Developers and providers of virtual-worlds and Web 4.0 solutions will need to perform extensive testing and validation during the integration and deployment phases to identify and resolve potential compatibility issues and vulnerabilities. This will be fundamental in the context of industrial virtual worlds, where technology providers will need to implement redundant systems and backup strategies to ensure continuous availability of critical processes and data in the event of failures or outages[182]. They will also need to apply robust cybersecurity measures, including firewalls, regular security updates, and employee training, to protect against cyber threats and minimise the risk of operational disruptions and downtime, which could affect productivity and cause financial losses that would have a huge impact on the industries, especially start-ups and SMEs.

The successful integration and engineering of new platforms and systems for virtual worlds and Web 4.0 will require technological excellence in multiple domains. EU telecommunication providers are already building expertise centres to deal with the complexity of integrating these technologies. An example is Telefonica, which has identified profiles such as cyber and virtual security experts, digital ecosystem developers, 3D programmers and designers, and digital marketing experts as the most sought-after professional profiles for virtual worlds[183].

When it comes to hardware, Varjo[184] (Finland), Vrgineers[185] (Czech Republic) and Lynx[186] (France) are probably the most relevant examples of EU SMEs and start-ups producing high-quality devices for professional immersive virtual-worlds experiences. These companies which mainly integrate components and design the headsets still depend on non-EU suppliers of electronic components and for manufacturing their devices.

[181] https://www2.deloitte.com/us/en/insights/industry/technology/metaverse-infrastructure.html
[182] https://www.sciencedirect.com/science/article/pii/S2213846322001833
[183] https://www.telefonica.com/en/communication-room/professional-profiles-in-the-metaverse-wich-ones-are-the-most-in-demand/
[184] https://varjo.com/
[185] https://vrgineers.com/
[186] https://www.lynx-r.com/

# 5 RELATED INVESTMENTS BY THE EUROPEAN COMMISSION

In terms of investment, the European Commission has funded targeted research and innovation in XR technologies for an amount of EUR 170 million since 2018, through the Horizon 2020 and Horizon Europe programmes

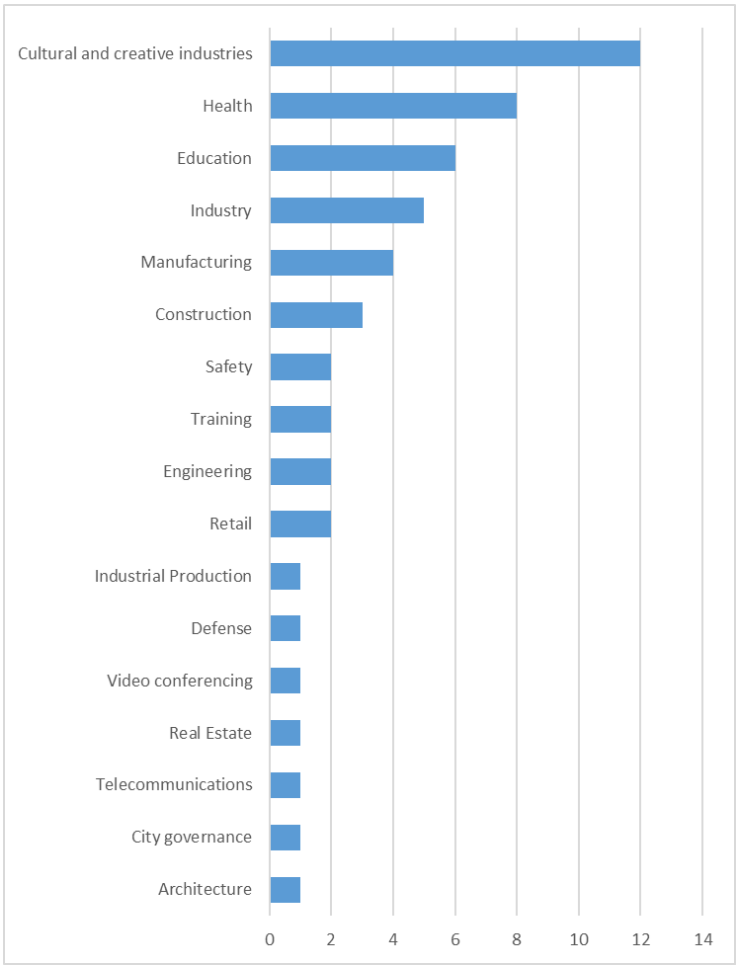


*Figure 16. EU funding of extended reality technologies per sector. Source: European Commission*

The H2020 calls on interactive technologies, ICT-25-2018-2020 and ICT-55-2020 provided funding opportunities aimed at supporting European industries and fostering a competitive and a sustainable ecosystem of European technology providers in interactive technologies.

The challenge under ICT-25-2018-2020 for Coordination and support action was to forge a competitive and sustainable ecosystem of European technology providers in interactive technologies and this task was accepted by XR4ALL.

The research and innovation actions focussed on multi-user interactions and higher quality experiences researching and developing technologies augmenting human interaction in groups.

One example is the ARETE project from the earlier call, which supported the use of Augmented Reality in education by building a pan-European competitive ecosystem for

fast dissemination of augmented learning content to a wide audience. Among the most important outcomes is the development of Read and Spell, an augmented reality app for learning English, the STEM app for learning geometry and geography, and the PBIS-AR app for use in behavioural lessons in primary school[187].

Another example, PRIME-VR2[188], which developed a collaborative VR rehabilitation environment that uses a gaming virtual space to provide stimulus, socialisation, and friendly competition for users on the path to rehabilitation from sports injuries, strokes, and movement disorders.

The ICT-55-2020 call was particularly focused towards funding the development of richer virtual environments, new user interfaces and improved immersion maximising the feeling of presence.

In the media sector, AdMiRe[189] received funding for developing innovative solutions using advanced mixed realities allowing for enhanced experiences for TV audiences and bringing radical improvement in talent immersion and interaction with computer-generated elements for content creators. One objective was to produce solutions that would allow viewers at home to be incorporated into the live TV programme and to interact with people in the TV studio.

Moreover, funding was granted to research and innovation actions developing high-fidelity virtual avatars. One such example is INVICTUS[190], a project aimed at developing avatars that can be integrated into movies, games, and immersive productions in augmented and virtual reality. For this purpose, digital solutions were created for transferring shapes between characters, performing stylisation of appearance, adapting, and transferring motions, as well as a story authoring tool allowing the immersion of storytellers in virtual representations of their stories.

Under Horizon Europe Cluster 2 there are various projects dealing with VR/AR and the cultural and creative sectors. A recently kicked off project, PERCEIVE, will advance the digital capabilities of scientists and cultural institutions through a service-based AI and image-based rendering architecture and toolkit, as well as a new design theory for on-site and remote XR and hybrid experiences based on concepts of care, participation and authenticity have recently kicked off. In the field of performing arts, another new project, PREMIERE, will lead to the development and validation of a comprehensive ecosystem of digital applications, powered by leading-edge AI, XR and 3D technologies, to meet the needs of communities involved in the main stages of the life cycle of performing arts productions

Besides, various projects funded by Creative Europe focus on the many possibilities brought by virtual worlds, such as NEWEN META SKY, a virtual creative marketplace dedicated to European creators and producers to help them develop, finance and promote their contents in the world; META STORIES, to experiment an innovative business,

[187] https://www.areteproject.eu/
[188] PRIME-VR2
[189] AdMiRe
[190] INVICTUS

distribution and promotion model, with the goal of gathering a young and international audience around European content, on the project European cultural XR network, on events, lab sessions and online content dedicated to opening the XR market and the metaverse to European cultural venues or Creative Web3 Experience Europe (CWXP) is a new framework for the audiovisual, cultural and creative sectors to test innovative digital solutions and business models, such as music and film festivals in the metaverse, monetisation through NFTs, and co-creation through blockchains. There also is the project Unlocking the Community on audience engagement.

In the current framework programme, Horizon Europe, during the cycle 2023-2024, the Commission will support the development and integration of advanced XR hardware components as well as the development of new solutions for creating virtual worlds and 3D models, realistic avatars and intelligent agents.

It will also build on approximately EUR 130 million of recent and planned investments under the Digital Europe Programme supporting the digital transformation of Smart Communities, creating the necessary building blocks and enhance Local Digital Twin solutions with virtual worlds technologies to create a European CitiVerse.

The Commission is also supporting the participation of European experts and SMEs in ongoing standardisation activities under the Digital Europe Programme in key relevant areas, such as blockchain and distributed ledger (that are necessary for virtual transactions), digital twins and CitiVerse technologies.

## 6 OVERVIEW OF RELEVANT EXISTING LEGISLATION

While the concept of virtual worlds has captured the attention of many, it is essential to recognize that its operation is not outside the purview of the existing EU regulatory framework. Rules that govern the digital realm also apply to virtual worlds, including laws related to data protection, privacy, consumer protection, worker´s rights and cybersecurity. The fact that virtual worlds operates differently than traditional digital services does not exempt them from regulatory compliance. It is crucial to assess the nature of a particular virtual worlds service to determine the legal obligations that providers of such services should comply with. Providers must ensure that their services are lawful, fair, transparent, and respect the rights of their users.

In virtual worlds, users can interact with each other, create content, and express themselves freely. Businesses will be able to provide tailored, innovative products and services to users, and also benefit from transformative B2B collaborations and partnerships. Public services, such as education, healthcare and government services, could also be delivered in this virtual environment. However, to make this vision a reality, it is crucial to build virtual worlds in a way that preserves trust and respect for fundamental rights. Virtual worlds must prioritize the empowerment of users with respect to their data, as well as to protect them from cybercrime and harmful content.

The EU has enacted key legislation to promote the respect for fundamental rights in the development and functioning of virtual worlds, such as:

- **EU Antitrust rules** promote effective competition by prohibiting agreements between market operators that would restrict competition as well as the abuse of dominant positions.
- **The Digital Markets Act** will provide tools to foster contestability in virtual worlds, either because the relevant services are within its scope or through the provisions that ensure future proofing of the Digital Markets Act.
- **The Digital Services Act** fosters innovation, growth, trustworthiness and competitiveness of the European single market. It introduces various layers of obligation on intermediary service providers, online platforms and very large platforms to remove illegal content. The DSA is crucial for the future development of safe virtual worlds in which consumers' fundamental rights and interests are protected. Moreover, through the proposed rules on how platforms moderate content, on advertising, algorithmic processes and risk mitigation, the DSA will ensure that platforms – and in particular the very large ones – are more accountable and assume their responsibility for the actions they take and the systemic risks they pose, including on disinformation and manipulation of electoral processes.
- **The proposed Artificial Intelligence Act** aims at protecting fundamental rights and the safety of the people by introducing a risk-based approach to address specific challenges brought by AI systems. The higher level of risk generated by AI system; the more transparency is required to put AI system on the market. Apart from ex ante measures, the Artificial Intelligence Act ensures the strong enforcement framework and monitoring of AI systems already placed on the market.
- **The proposed AI Liability Directive (AILD)** introduces liability rules that allow the victims of accidents caused by AI systems to prove successfully their liability claim, including compensation. The victims of AI should enjoy the same level of protection for damage caused by AI as victims of other technologies. The approach is very targeted as the proposal only deals with those aspects of liability rules challenged by AI specificities.
- **Network and Security Directive (NIS2)** sets out the baseline for private and public entities to ensure high common level of security across the EU and mitigate cybersecurity threats to the essential services in key sectors such as ICT service management, some areas of public administration, digital infrastructure including TLD name registers, public communication networks, publicly available electronic communication services.
- **The proposed Cyber Resilience Act** enhances digital security through mandating manufacturers of connected objects to demonstrate conformity with essential security requirements and vulnerability procedures. One of its aims is to ensure an EU-wide cybersecurity framework which facilitates compliance for software products.
- The **proposed European Health Data Space Regulation** enables to empower individuals to control and access their electronic health data and provides consistent framework in secondary use of data.
- Crypto-assets will be regulated by the proposed **Regulation on Markets in Crypto-assets (MiCa)**, and **Regulation for a pilot regime for market**

**infrastructures based on distributed ledger technology (DLT Pilot regime).** Crypto-assets will play a crucial role in virtual worlds-related transactions by enabling free flow of capital between users and businesses.

- **The Unfair Commercial Practices Directive** establishes a high level of consumer protection by prohibiting aggressive and misleading commercial practices, including in advertising. Taking into account the immersivity of the virtual worlds, it is important to protect consumers from unfair influence on their commercial decisions. The Commission is also currently reviewing EU consumer protection legislation to ensure its continued effectiveness regarding digital fairness.
- **The proposed Data Act** encourages more actors to participate in a data-driven economy. It will contribute to the establishment of robust data sharing environment across sectors and in particular in the Internet-of-Things context. In addition, the Data Act will enable cloud customers to easily switch between different data-processing services providers.
- **The Proposed recast of Directive 2011/93/EU** on combating the sexual abuse and sexual exploitation of children and child pornography will be presented by the Commission by the end of 2023, which will aim to combat new offences including sexual abuse offences committed against children in the metaverse.
- **The Proposed Regulation on preventing and combatting the sexual abuse and sexual exploitation of children**, which lays down uniform rules to address the misuse of relevant information society services for online child sexual abuse in the internal market.
- **Directive (EU) 2019/713** on combatting fraud and counterfeiting of non-cash means of payment.
- **Directive 2013/40/EU** on attacks against information systems.
- **Directive (EU) 2017/541** on combatting terrorism, where these offences are wholly or partly committed by means of an information system.

The following four sections will look in closer detail at four of the main areas of concern in this regard, namely personal data protection, protection of intellectual property rights and other related rights, user empowerment and cyber-crime in virtual worlds.

### 6.1 Data protection

The unprecedented volume and nature of data collection in virtual worlds (e.g., biometric data, as well as data on users' movements, interactions, and behaviour) may lead to complete user surveillance and raise, therefore, concerns about user's privacy and protection of their personal data. Stakeholders have repeatedly voiced this concern. It is crucial to ensure that personal data collected in virtual worlds is processed in compliance with EU data protection law, in particular the GDPR. EU data protection law lays down data protection principles and obligations, such as the purpose limitation, data minimization, and transparency principles. Virtual worlds should operate in line with these principles and rules and ensure that the users remain in control over their data, for instance by means to easily exercise their rights to information, access, erasure, portability. As virtual worlds continue to evolve, it is essential to monitor its data processing practices and ensure that they adhere to the GDPR's requirements.

Special categories of personal data, such as data related to health, require enhanced protection and the processing is subject to strict requirements, including on the situations permitting such processing. As virtual healthcare services become more common in virtual worlds, it is crucial to ensure that robust measures are in place to protect such data, including organisational and data security measures.

Finally, it is important to address the need for user identification in virtual worlds in compliance with the data protection law. Digital identity and anonymity present complex issues and determining under which conditions users should be asked to reveal their identity is critical. While identification under certain circumstances may be necessary to prevent illegal activities such as money laundering or terrorism financing, it is essential to ensure that the process is transparent, and that user privacy is respected and complies with GDPR rules, such as that such processing is based on a lawful ground, and principles, such as the principle of data minimisation and transparency. Users must be provided with clear information about why identification is necessary and how their personal data will be handled. In line with the GDPR, this includes finding effective ways to inform users about various aspects, such as the specific purposes for which their personal data will be processed, the personal data that will be collected, and the retention period of this data. By being transparent about their data processing practices, businesses and platforms can help to build trust with users and ensure that the users can exercise their other rights, such as the right to access and erase data related to them.

## 6.2 Intellectual property rights (IPR)

Virtual worlds have the potential to serve as a platform for renewed artistic expression and serve as a boost to human creativity, while also creating numerous business opportunities. In particular, virtual worlds provide new ways of creating and handling content protected by intellectual property rights.

### *6.2.1 Copyright*

The EU's legal framework for copyright and neighbouring rights consists of 13 directives and 2 regulations. The most important copyright legal acts from virtual worlds' perspective are the Digital Single Market (DSM) Directive[191], InfoSoc Directive[192], Intellectual Property Rights Enforcement (IPRE) Directive[193], and Software Directive[194].

Copyright and neighbouring rights protection and management may be highly relevant in relation to both architecture of virtual worlds (i.e., the software, computer programmes, website designs underpinning virtual worlds) and also regarding the works and other subject matter placed in virtual worlds by developers, users or artificial intelligence (art, avatars, story, music etc.).

Copyright and neighbouring rights legislation confer moral and economic rights on the authors and other relevant right-holders. Even though copyright rules are largely harmonised in the EU (in particular as regards economic rights and exceptions), certain

[191] https://eur-lex.europa.eu/eli/dir/2019/790/oj
[192] COM(2022) 548 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001L0029
[193] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0048
[194] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32009L0024

rules are provided for in the legal frameworks. For example, moral rights are not harmonised at the EU level. It is uncertain how enforcement of author's and performer's moral and economic rights across virtual worlds will be addressed by national courts.

It is expected that trading of protected assets will often rely on NFTs. While NFTs certify the ownership of a digital carrier (i.e., a file, metadata or software code), NFTs do not automatically convey copyright (copyright protection applies to the creative work itself). Nevertheless, the use of NFTs in virtual worlds may raise numerous copyright-related challenges. At its core, building awareness of the consequences of transactions involving NFTs is important. Moreover, it is not clear whether minting or storing NFTs on the blockchain is an exploitation of a copyrighted work. If doing so constitutes copyright infringement, the full destruction of the infringing NFTs may be difficult. However, blockchain may be useful tool for evidentiary purposes in copyright infringement cases.

Apart from the engagement of human actors in the development of virtual worlds, AI is also an important component. The interplay between AI and copyright is complex and raises two types of challenges. The first type of challenge concerns the use of copyright protected content to train AI applications, the second type of challenges relates to the protectability of AI-generated content and the possible competition with human creations. The DSM Directive includes a general text and data mining (TDM) exception, which is particularly relevant in the context of AI models being trained on copyright-protected content. Regarding the protection of AI-generated content, the EU copyright law requires for the copyright protection that the work is the result of the human effort reflecting the "author's own intellectual creation". Therefore, if AI systems generate output without human creative choices, such an output is normally excluded from the copyright protection.

Finally, copyrighted virtual objects created by users are usually tied to terms and conditions of platforms. It is necessary to monitor whether platforms may force users to grant non-exclusive free-of-charge licenses to their works to the platform itself or other users in order to make sure that those practices do not deprive users of a significant part of profits that their works may generate on that platform.

### *6.2.2 Trademarks*

The EU legal framework for trademarks consists of Regulation (EU) 2017/1001[195] and Directive (EU) 2015/2436[196].

The number of applications for EU trademarks is increasing for various types of virtual goods or NFTs. The EUIPO Guidelines[197] give details on the full applicability of the Nice Classification for virtual goods. However, there are questions regarding the territorial use of a trademark across virtual worlds and it is also not clear whether the use of a trademark in respect of a virtual product constitutes genuine use in respect of a real-world product covered by a trademark registration.

[195] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017R1001
[196] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015L2436&qid=1683211445598
[197] EUIPO Guidelines (europa.eu)

As the number of trademark infringement cases grows in virtual worlds (e.g. by embedding the trademark into NFTs) it will be necessary to examine whether trademark protection needs to be strengthened by legislative means in virtual worlds. It is also not yet clear how to handle legal disputes involving a comparison of physical and virtual goods or services.

### *6.2.3 Designs*

Visual appearance of the products resulting from their features is protected by Directive 98/71/EC[198] and Regulation (EC) 6/2002[199]. The provisions on designs will be updated by the Proposal for a Directive[200] and Proposal for Regulation on Union designs[201].

The challenges brought forth by virtual worlds include the protection and registration of a virtual products including NFTs as designs, disclosure of unregistered designs, design protection requirements, classification of products, use of unregistered or registered designs and ensuring legal certainty in virtual design infringement proceedings.

### *6.2.4 Trade secrets*

Trade secrets are protected by Directive (EU) 2016/943[202] on the protection of undisclosed know-how and business information. Commercially sensitive information generated in the context of a 'virtual office' needs to be protected from unlawful acquisition by the holder/provider of virtual worlds.

The Data Act takes a balanced approach regarding protection of trade secrets in the context of the access and use of data generated by connected products by consumers and businesses.

### *6.2.5 Enforcement of IPRs*

The protection of intellectual property rights and trade secrets in the context of virtual worlds must be ensured. Nevertheless, enforcement in virtual worlds may be uniquely challenging. For instance, given the cross-border nature of virtual worlds, determining a territorial aspect of IPR infringement may raise difficulties. Lack of users' identification in virtual worlds should not exclude the possibility to assign liability for infringement of IPRs. Moreover, it would be important that all entities engaging in virtual worlds would be adequately covered by the rules related to IPR enforcement.

## 6.3 Empowering people and businesses

In the Commission work programme 2023[203], the Commission announced that it "*will propose tools on developing open human-centric virtual worlds, such as metaverses. These provide a myriad of possibilities for industries and service sectors, the creative arts and citizens, as well as opportunities to address broader social challenges*". Empowerment is the key principle for designing human-centric virtual worlds.

[198] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31998L0071
[199] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002R0006
[200] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0667
[201] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0666
[202] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016L0943
[203] https://commission.europa.eu/system/files/2022-10/com_2022_548_3_en.pdf

The Commission's Data Strategy of 2020 and the legislation being put in place within its framework (namely, the Data Governance Act and the Data Act) aims at empowering citizens and businesses to have more control over their data, thanks to clear and fair rules on access and re-use of data. This includes the reinforced role for data intermediaries as trustworthy organisers of data sharing, tools for citizens and businesses to make their data available for the benefit of society, as well as better access to data collected or produced by devices. The emerging virtual and hybrid environments will present new challenges in this respect.

To ensure empowerment in virtual worlds, users must have the choice to remain anonymous if it is not necessary to identify them for a legitimate purpose. At the same time, in case where it is required to ensure legal effects of user's actions or protect safety and trust of other users, there should be tools available to authenticate a user's identity. Managing digital identities should provide a high degree of trust to and for the user. Users should own, maintain and control their digital identity through human-centric and personal data protection compliant technologies. There should be the possibility to porting one's data – including digital assets, attributes and activities – between virtual worlds. Digital identity providers need to be trusted entities that can ensure lawful data processing. Such providers should not have unlimited access to the user's data.

The upcoming EU Digital ID Regulation[204] aims at giving full control to users over their identity in their private and public transactions. They will be able to prove their identity and share electronic documents from their European Digital Identity Wallet (EDIW). The EDIW allows users to, among others: store identity data, credentials and attributes linked to their identity and provide them on request; provide authentication services; create qualified electronic signatures; and store and exchange the information provided by trusted private sources.

Virtual worlds have the potential to bring citizens closer to shaping the public policies and influence democratic processes in general, without constraints of geography or location.

The Charter of Fundamental Rights of the European Union underlines that the EU is based on the principles of democracy and the rule of law and these principles apply in the virtual worlds as well.

The protection of equality and non-discrimination in the context of virtual worlds must be ensured. The EU has extensive legislation on equal treatment irrespective of sex, "racial origin", ethnic origin, disability, age, religion or beliefs, and sexual orientation[205].In addition, it is crucial that the virtual worlds support and ensure equality and non-discrimination in access to and the supply of goods and services, education, social protection and employment, in line with the EU equality legislation.

Trustworthiness of democratic processes and developing its potential for the economy will depend on how virtual worlds will be able to ensure security of public and private transactions of their users. They have to provide robust tools preventing fraud (concerning

[204] COM(2021) 228 final. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-digital-identity_en

[205] Directive 2000/43/EC of 29 June 2000.

both identity and financial assets). There are rules in place in Directive (EU) 2019/882[206] (European accessibility act) and initiatives in place such as the new European strategy for a better internet for kids (BIK+). The relevant rules will need to be properly enforced and their effectiveness related to virtual worlds should be monitored[207].

### 6.4 Cyber-crime

The use of virtual worlds will also increase concerns relating to cyber-crime and cyber-enabled crime. Certain types of cybercrime, such as ransomware, may have worse consequences in the virtual worlds given the increasing importance of digital assets in them.

The enhanced use of digital identities in the metaverse may also lure criminals, who may find new ways to impersonate or steal the users' identity.

The economic aspects of the metaverse, including the use of virtual money and transactions involving NFTs may raise new challenges in countering money laundering and online fraud.

Other criminals in areas such as harassment and (child) abuse and exploitation, and terrorism may also try to exploit virtual worlds to facilitate their criminal activities.

There is a risk that the exponentially higher amount of personal data circulating in Web 4.0 may be used to obtain even more precise insights into people to influence their behaviour, whether for commercial or political gain, and to carry out more effective misinformation campaigns.

These risks need to be adequately factored into the development and the governance of the virtual worlds from the outset[208].

In this sense, the EU has several rules already in place to protect users in the virtual space: Directive (EU) 2019/713 on combatting fraud and counterfeiting of non-cash means of payment, Directive 2011/93/EU on combating the sexual abuse and sexual exploitation of children and child pornography, Directive 2013/40/EU on attacks against information systems and Directive (EU) 2017/541 on combatting terrorism where these offences are wholly or partly committed by means of an information system.

## 7 GLOSSARY

| Term or acronym | Meaning or working definition – the proposed definitions are for the sole purpose of this document and its understanding |
|---|---|

[206] https://op.europa.eu/en/publication-detail/-/publication/6eb3ceb5-8905-11e9-9369-01aa75ed71a1/language-en/format-PDF/source-285457991

[207] Hupont Torres, I., Charisi, V., De Prato, G., Pogorzelska, K., Schade, S., Kotsev, A., Sobolewski, M., Duch Brown, N., Calza, E., Dunker, C., Di Girolamo, F., Bellia, M., Hledik, J., Nai Fovino, I. and Vespe, M., Next Generation Virtual Worlds: Societal, Technological, Economic and Policy Challenges for the EU, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/51579, JRC133757.https://publications.jrc.ec.europa.eu/repository/handle/JRC133757.

[208] Euopol (2022). Policing in the metaverse: what law enforcement needs to know

| | |
|---|---|
| Augmented reality (AR) | Interactive technology that integrates digital information with the user's physical surrounding in real-time. It enhances the user's perception of real-world objects and environments by overlaying digital sensory inputs onto them. AR can be experienced through a variety of devices, including smartphones, tablets and smart glasses. |
| Avatar | Digital representation of a person or user within a virtual world. |
| Blockchain | Technology that allows a network of computers, rather than a central authority, to maintain and update a shared and synchronised digital database or a ledger of proof of ownership with verified, immutable data, based on a consensus algorithm and stored on multiple nodes. |
| CitiVerse | A CitiVerse is a series of interconnected distributed hybrid and virtual worlds representing, and synchronised with, their physical counterparts and offering virtual goods/services/capabilities (in the areas of administrative, economic, social, policy-making, and cultural activity) to city and community actors. |
| Citizens' panel | Innovative democratic instrument that puts citizens at the centre of public policymaking. Randomly selected citizens from all 27 EU Member States come together to discuss key forthcoming proposals at the European level and make recommendations that the European Commission will take into consideration when defining its political goals and concrete policies. |
| Data Spaces | Data infrastructure, data governance framework and data-related services (such as tools for pooling, processing and sharing data between entities and data structures) aiming to foster availability, quality and interoperability of data – both in domain-specific settings and across sectors. |
| Decentralised Autonomous Organisations (DAO) | Type of organisation where rules and decision-making processes are encoded on a blockchain network. DAOs are controlled by their members, who collectively make decisions through a transparent and decentralised governance structure, without the need for a central authority or hierarchical leadership. Smart contracts, digital protocols, and blockchain technology are used |

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| | to enforce the DAO's rules and ensure that decisions are made democratically and transparently. |
| Digital asset | Digital representation of value that can be traded, transferred or used for payment. It has specific usage rights and can include anything from cryptocurrencies to digital art and other forms of intellectual property. |
| Digital wallet | Type of online storage that lets you securely keep track of your digital assets and information, like digital certificates and digital identity information. It's like a traditional wallet but for your digital items and credentials. It can easily be used for your assets and information in a variety of online transactions and activities, like virtual worlds. |
| Digital identity | Collection of data that uniquely represents an individual or organisation in the digital world. Digital identity is used for authentication, authorisation and verification purposes online. It includes the digital footprints left behind while using digital services. |
| Digital twins | Digital representations of real-world entities or processes. Digital twins use real-time data and numerical models to simulate future developments and test scenarios. |
| Distributed ledger technology | Technological infrastructure and protocols that allow simultaneous access, validation, and record updating across a networked database. Distributed ledger uses cryptography to confirm, carry out, and secure actions and transactions. |
| European Digital Infrastructure Consortium (EDIC) | EU policy instrument aiming to help Member States speed up and simplify the setup and implementation of multi-country projects. Proposals of EDICs can be submitted by a minimum of three Member States. Each consortium will have its own legal personality, governing body, statutes, and seat in a participating Member State. |
| Extended Reality (XR) | Collective term referring to immersive technologies such as virtual reality (VR), augmented reality (AR) and mixed reality (MR) which enhance reality and our senses by adding digital |

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| | information to the real world or creating a new digital environment altogether. |
| High Performance Computing (HPC) | Computing at performance levels requiring the massive integration of individual computing elements for solving problems which cannot be handled by standard computing systems. Synonym for supercomputing. |
| Horizon Europe partnership | European Partnerships with EU and associated countries, the private sector, foundations and other stakeholders with the aim to deliver on global challenges and modernise industry. |
| Internet Governance | Development and application by governments, the private sector, civil society and the technical community, of shared principles, norms, rules, decision-making procedures, and activities that shape the evolution and use of the Internet. |
| Local Digital Twin | A virtual representation of urban or rural (local) physical assets, processes and systems which is also connected to all the data related to them and the surrounding environment, as well as other assets in the same way as the physical assets, so that artificial intelligence algorithms, data analytics and machine learning can be used to help the city operate more efficiently. |
| Metaverse | Interoperable network of virtual worlds. |
| Non-Fungible Token (NFT) | A unique and non-interchangeable unit of data stored on a digital ledger (blockchain). NFTs can be associated with reproducible digital files such as photos, videos, and audio. NFTs use a digital ledger to provide a public certificate of authenticity or proof of ownership, but it does not restrict the sharing or copying of the underlying digital file. |
| Regulatory sandbox | Structured context for experimentation that enables the testing - in a real-world environment - of innovative technologies, products, services or approaches for a limited time and in a limited part of a sector or area. This is done under regulatory supervision and ensuring that appropriate safeguards are in place. |
| Web 3.0 | The 3rd generation of the World Wide Web aims to enable smarter interactions between users and systems by making data |

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| | more discoverable and accessible (i.e., machine readable) through the use of metadata and linked data technologies such as RDF, SPARQL, OWL, and SKOS. |
| Web 4.0 | 4th generation of the World Wide Web where physical and digital worlds are seamlessly blending, enabling more intuitive and immersive experiences. Making use of advanced artificial and ambient intelligence, internet of things, virtual worlds and extended reality capabilities, web, real objects and environments are fully integrated and communicating between each other through more collaborative, decentralised and user-centered approaches. |
| Virtual reality (VR) | Immersive technology that allows users to interact with virtual objects and other users in 3D environments. Using head-mounted displays, tracking systems and controllers VR users feel fully immersed in virtual worlds. |
| Virtual worlds | Persistent, 3D, real-time, immersive environments, blurring the line between real and virtual, for socialising, working, learning, making transactions, playing and creating. |

# ANNEX 1: FACTUAL REPORT ON THE STAKEHOLDER WORKSHOP CONSULTATIONS

## WORKSHOPS ON VIRTUAL WORLDS

**Disclaimer: The views presented in this factual summary report are not the views of the European Commission but of the stakeholders who participated in the consultation. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

BACKGROUND

In support of the EU initiative on virtual worlds, the EC convened a series of workshops with the view of collecting opinions from a broad range of the stakeholders, coming from different European industry sectors, universities and research centres or affiliated to the VR/AR coalition.

METHODOLOGY

Between January and March 2023, the 5 workshops organised by the EC gathered 121 participants, who had accepted the invitation sent to them individually. The main criteria for selecting the workshop audience were sectoral representativeness at EU level, prominent place on the market and medium-to-high uptake of innovative technologies (for industry/ tech representatives), specialised knowledge and excellence in research work (for academia and research), and active contribution to EC-led initiatives (for the VR-AR coalition). To increase engagement, each workshop hosted in average 24 participants, who discussed both in small groups (6-8 participants) and in the plenary. The group exchanges in all workshops followed a pre-defined structure, under the form of targeted questions:

1. *What are the most important **benefits** that virtual worlds can bring to your sector and the ways in which the EC can help you to realise them?*
2. *What are the **challenges** for the uptake of virtual worlds in your sector and the ways in which the EC can help you to tackle them?*
3. *How should the EC enhance **collaboration** between virtual worlds/metaverse stakeholders and **raise awareness** of the EU market?*
4. (Optional) *Could you identify 3 deployed use cases of virtual worlds in your sector that you would qualify as success stories for the EU?*

To ensure a high level of quality of the discussions and, ultimately, of their output, each workshop targeted certain categories of stakeholders:

- 2 workshops welcomed lead representatives of 27 businesses active in different industry branches (e.g., CCIs, education, media, aerospace, automotive) and 28 technology providers of hardware, platforms and tools, needed to build Virtual words (e.g., 3D, headsets manufacturing, XR, digital twins, telecommunications).
- 1 workshop was dedicated to academia and research. It counted 12 university professors and 15 representatives of research institutes and labs.

- 2 workshops were aimed at gathering views from members (25 attendees) and, respectively associations representatives with an active role in supporting the VR-AR coalition (14 attendees), an important EC flagship initiative.

Concerning the geographic coverage, 21 Member States were represented, with a high number of participants from France (21), Germany (18) and Spain (16), followed by the Netherlands (10), Italy and Finland (7, each).

CONCLUSIONS

The participants provided their feedback as replies to the above questions and reached consensus on the following aspects:

1. **Main potential benefits of entering virtual worlds**

- **Closer connections** between people, networking, potentially creating virtual communities through new ways of interacting**.** Virtual words can trigger an increase in **public participation and co-creation.** They extend human cognitive abilities (telepresence, on-demand knowledge access, communication)
- Facilitation of **learning and training** - Virtual words allow for a better visualisation of complex and abstract subjects, enhanced interaction and engagement in the experience, improvement of memory retention. They can help with training professionals in extreme scenarios (e.g., healthcare, firefighting)
- More **immersive entertainment** (e.g., live shows)**, better cultural experiences** (e.g., new opportunities to maximise access to Europe-based heritage for young people)
- More productive **business collaborations** (e.g., for shared projects), improvement of industrial and business **processes**, **cost saving**, increase in **productivity**, Time-to-Market benefit. Virtual words offer the possibility to come up with better **innovations of products and services** by digital sharing/testing, with less material used during development.
- Improvement of **customer experience; collaboration between industries and people** based on generalised business values and digital identity (e.g., with a trustable ID, users identify providers in virtual words and avoid fakes /fraud).
- **Boost of creativity** in the media sector through new ways of storytelling, reaching new and more inclusive audiences; language diversity
- **Sustainability** (environmental, economic, societal), focus on **Sustainable Development Goals** (e.g., quality education, reduced inequalities). Ecological benefits – for example, in virtual words, virtual products can replace the need for certain types of physical good, traveling and building of things can be reduced. Gathering and sharing data for climate transition, and for cities to help planning processes are also important possibilities.
- New economic opportunities generated by virtual words which facilitate/automatise the scalability of **content distribution**,
- **Multiplicity** – there are several virtual worlds: social, enterprise, industrial
- **Labour market opportunities:** the opening of a **new economy of service,** easier **inclusion of young people** into different work areas where they can work virtually.

2. **Main perceived challenges posed by virtual worlds**

- **Dependence on non-EU sovereignty loss risk**, - Dangers of US and Chinese hardware providers and lack of an EU platform for virtual worlds.
- The **lack of EU standards** is a serious problem (for interoperability, for industrial sectors, for users). Positioning in relation with existing industry vs. international standards
- **Technological and ergonomic limitations** (e.g., lack of user-friendly headsets, interfaces and poor variety of displays) Uptake of the current devices is low. Competitive EU hardware equipment providers are missing.
- **Lack of IT infrastructure** (networks, HPC, cloud, etc.)
- **Poor knowledge** about virtual worlds; it comes with the risk of disinformation
- **Privacy and ethics-related issues** (e.g., when using smart glasses), as hosting infrastructure is mainly handled by US companies). Risk of acculturation.
- EU workers' **lack of adequate skills**/ familiarity to handle software, hardware, embodiment (e.g., limited adoption of digital twins in the industries).
- Potential **environmental impact** cause by the increase in server capacity
- Limited availability of open data from **public** authorities

## 3. EU support – where and how would be needed

### *a. Actions*

- **Standardisation –** perceived overall as a broad area for support. Among the ideas expressed on potential EC support:
  - Drive the creation of interoperability standards between virtual words
  - Help ensure global standards, keeping EU values (e.g., ethics) and trust and supporting green transition
  - Put in place an industry-led standards regime
  - Focus on interoperability and scalability, have virtual worlds sharing data and information between them; support open-source solutions
  - Create a permanent body promoting quality standards and providing advice and resources to national policy makers and organisations
  - Support standards and open protocols for the European players (SMEs, research labs and entrepreneurs) in software and hardware development, 3D modelling, etc.
  - Foster the creation of accounting standards for valuation of virtual assets
  - Digital ID-related standards - Shared identities – to prevent lock-in and allow transfer between digital worlds (common EU digital identity mechanism)
  - Create a "quality" label for SMEs and larger audiences as a guidance to start navigating virtual worlds: conformity to EU standards.
- Creation of a **European ecosystem** to bring together companies and players, and protect European companies; Nurture a tech and creative **talent** ecosystem; Support a world-class cloud computing infrastructure for the ecosystem
- Investment in **infrastructure**, supporting XR scenarios in current **5G and Cloud initiatives** (e.g., Gaia X) with a focus on optimisation. EC should foster Member States' agreements on common EU solutions for infrastructure.

- Investment in education/ training/ skill development; a multidisciplinary set of skills is needed. Young talents should stay in the EU.
- Support of **human-centred** methodologies (e.g., participatory design) in interface/tools and application creation
- Integration of a **pro-innovation** mentality to policymaking (e.g., innovative spectrum policy); streamline industry/academia **innovation** (mapping services/development/funding)
- Consolidation of the legal framework for virtual words, no over-regulation, the balance should be maintained between regulation and business models
- Encouragement of the diversity in terms of platform creation, prefer the **more specialised ones**
- Protective measures to prevent drain/ commercializing of data outside EU; **Security and privacy** should be EC responsibility in the EU, from legislation to user education
- Clarification of the terminology related to the concepts and notions related to "virtual worlds"; definitions using common words are needed; many buzzwords are circulating.

*b. Mechanisms*

- **Funding** – More Public Private Partnerships, accelerate the funding process, focus on R&D, start-ups, academia
- **Workshops** to bring people together, facilitate synergies between players (e.g., discuss/define standardisation)
- Awareness raising on the **diversity of virtual words** (social, industrial), on the **impact** on population, business leaders and stakeholders, on the importance of **understanding the technology** behind the products; initiatives to bring XR to classrooms etc.
- Regular networking events to facilitate awareness on immersive technologies
- **Guidelines and best practices** based on EU common vision on virtual words, in an open source/knowledge library
- **Platforms** of various kinds: forum to exchange/ **share knowledge**, ideas, best practices at EU level; platform to **share results** on EU and national funded projects; platform-marketplace for **ongoing initiatives** and VW-relevant new technologies).
- Initiatives such as local pilot projects (e.g., group of people with specific needs), living labs in different areas to have a real impact, pilot projects integrating partnerships for awareness raising, a flagship project to unite all players (SMEs and big companies) etc.
- Festivals, events, hackathons; touring exhibitions organised by the EC for end-users to test freely immersive experiences; experience hubs across Europe available to the wider public.

# ANNEX 2: FACTUAL REPORT ON THE CALL FOR EVIDENCE

# Factual summary report of the public consultation on Virtual worlds (metaverses) – a vision for openness, safety and respect

*Disclaimer: The views presented in this factual summary report are not the views of the European Commission but of the stakeholders who participated in the consultation. It cannot in any circumstances be regarded as the official position of the Commission or its services. Responses to the consultation activities cannot be considered as a representative sample of the views of the EU population.*

## Objectives of the Consultation

The public consultation aimed to collect the views from stakeholders, citizens and individuals on the development of virtual worlds and Web 4.0 in line with EU values. The consultation ran from 05 April 2023 until 03 May 2023 on the Commission's "Have your say" portal. The overall number of responses submitted was 169. This number includes 2 duplicates that were removed, resulting in 167 responses that will be subject to analysis. The factual summary report provides an overview of the number of responses, some characteristics of the respondents as well as some of their views and concerns

## Information about the respondents

The consultation targeted a broad range of stakeholders according to their interest and expertise in the subject of virtual worlds. These include individuals, public authorities (Member States, regional and local public authorities, international organisations), businesses (large-size and SMEs, microenterprises, self-companies, consulting firms), research and academia, standardisation bodies, non-governmental organisations and social partners and representatives of professions and crafts (Chambers of Commerce, Trade Unions and other profession representatives).

A total of 167 respondents have contributed to the public consultation. As illustrated in Figure 17, 42 responses came from EU citizens (25.15%) and only 1 from a non-EU citizen (0.60%). The other 124 respondents can be broken down as follows: 31 business associations of which 3 are non-EU (US); 9 academics/researcher institutions of which 1 is non-EU (US); 4 organisations (3 consumer organisations and 1 environmental organisations); 6 public authorities; 2 trade unions; 30 Company/business (21 Large (70%), 3 Medium (10%), 2 Small (7%), 4 Micro (13%)) being 9 non-EU (mostly from UK and US and also from China and Switzerland); 24 non-governmental organisations

(NGO) of which 7 are non-EU (US and UK); and 18 other (i.e. respondents who identified themselves under this group).

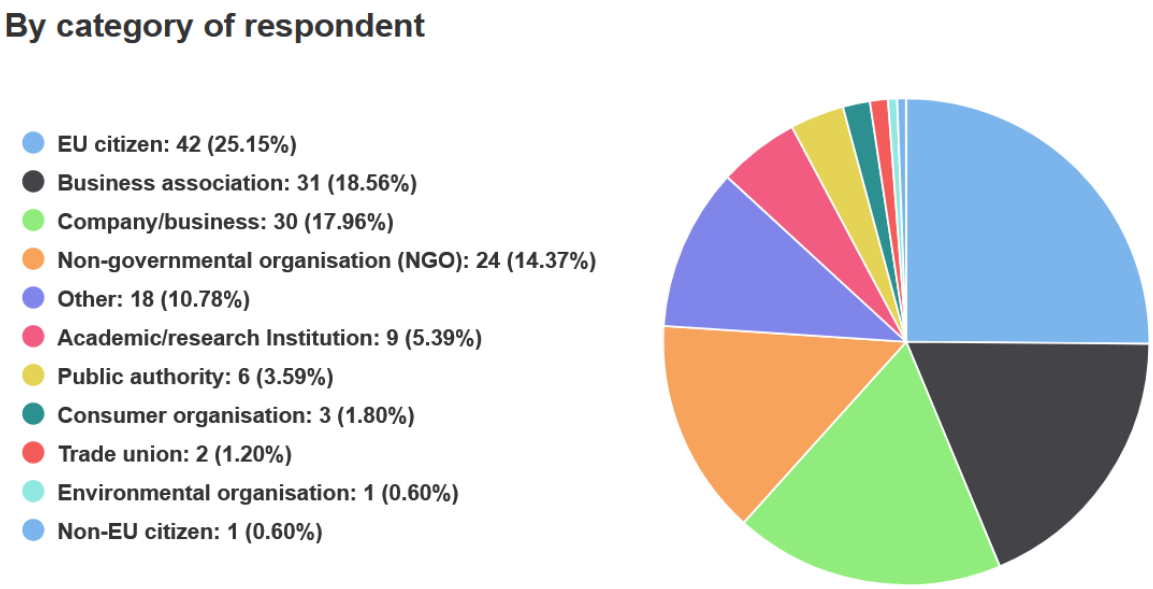


*Figure 17. Classification of respondents by category. Source: European Commission*

The consultation was available in 24 official languages. There are 17 EU Member States represented among the contributions (Figure 18), being the majority of the respondents from Belgium (19%), Germany (11%), Slovakia (11%), France (11%), Spain (8%), Italy (7%), Finland (6%) and the Netherlands (4%).

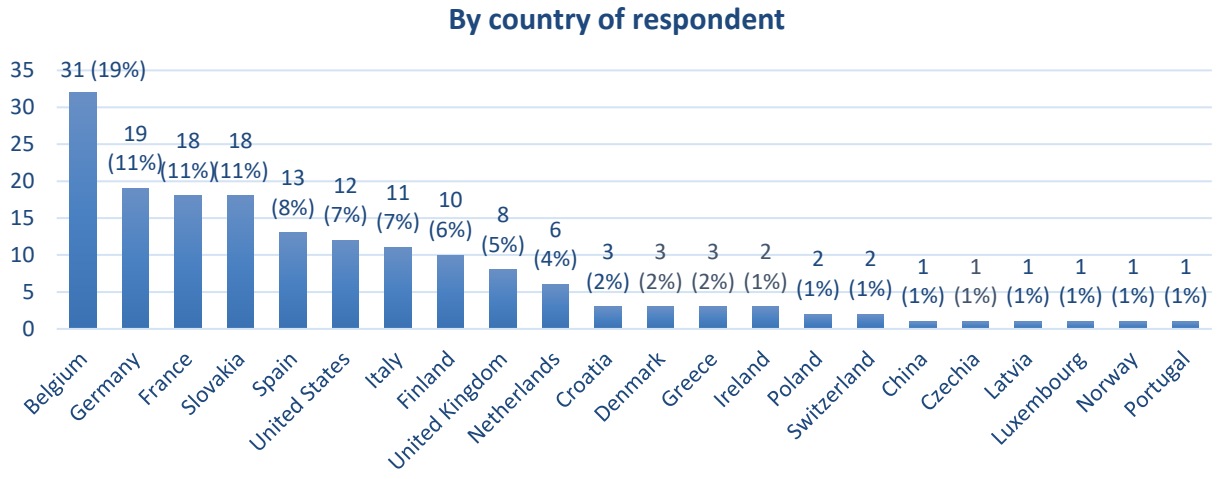


*Figure 18. Classification of respondents by country. Source: European Commission*

The non-EU countries most represented among the contributions are Unites States (7%) and United Kingdom (8%), but contributions also came from Switzerland, Norway and China.

## Preliminary findings observed in the replies

The open format of the public consultation allowed respondents to express their views and input on the future actions the Commission can put forward in relation to the development of virtual worlds and Web 4.0 following its vision of openness, safety and respect.

Most of the respondents (59% - 99 of 167), mainly business associations, companies/businesses and NGOs expressed a positive sentiment towards virtual worlds and Web 4.0 in general and suggested different recommendations for the European Commission to take into account when developing the initiative. In contrast, some participants (14% - 24 of 167), almost all of them EU individuals, positioned themselves as against the initiative or expressed concerns about virtual worlds and digitalization in general. There rest of respondents (26% - 44 of 167) had a neutral sentiment towards the subject and do not position themselves either in favour or against the development of virtual worlds or the initiative.

The replies of the respondents have been classified following the four cardinal points of the Digital Compass (skills, businesses, infrastructures and government), within the Digital Decade policy programme209 and together with the 6 principles of the Declaration on Digital Rights and principles (People at the centre, Freedom of choice, Safety and security, Solidarity and inclusion, Participation, Sustainability), as they are key points of reference for setting the path towards a human-centred, sustainable and prosperous digital future.

### Digital Compass

Skills

Skills and education on how to use virtual worlds was considered necessary for the uptake and acceptance of virtual worlds by 20% of respondents (34 out of 167). Of those respondents most of the half (62% - 21 out of 34) were companies/business and business associations. These respondents emphasized the need to address the increasing scarcity of qualified professionals in the virtual-worlds industry (e.g., developers, creatives, etc.). Companies and business associations call for prioritization of the development of technological skills (upskilling, reskilling) in relation to virtual work and how these skills should be also learnt from early age. Thus, having virtual worlds an impact in the education sector (from a curricula point of view and new ways of teaching) and requiring specific public funding. Because of that, especially Business associations, NGOs, public authorities and trade unions brought to the front the importance of making virtual worlds inclusive and accessible, so people have equal access to them from the beginning.

Digital transformation of businesses

[209] DECISION (EU) 2022/2481

Almost half of the respondents (56% - 93 of 167) expressed their views on digital transformation of businesses in the area of virtual worlds and Web4.0. Some participants highlighted the need for support of research, development and deployment of virtual-worlds and Web 4.0 underlying technologies through EU funding programs. This is especially important in relation to industrial scenarios, which have the potential to drive significant economic growth and job creation. According to some participants, there is a pressing need to stimulate and accelerate the adoption of virtual-worlds and Web 4.0 technologies in the EU, which is low compared to other parts of the world, due in part to an insufficient awareness among the EU businesses of the potential brought by these technologies.

The existing EU regulatory framework for the digital space, particularly the Digital Markets Act and Digital Services Act, was mentioned by 14% of respondents (23 of 167) as relevant to virtual worlds/Web 4.0 platforms and related services. However, it was often recommended that the development of further regulatory measures should be flexible and adaptive to keep pace with the fast-changing technological landscape and in order not to hinder innovation and competitiveness of the EU businesses. Some respondents recommended that the EU should promote the adoption of common industry practices related to virtual worlds and Web 4.0 through soft law instruments, such as recommendations, guidelines, and codes of conduct. Additionally, it was suggested that new regulations should only be introduced in cases where there is a significant risk of rule fragmentation in the Single Market.

Moreover, 3% of respondents (5 of 167) – that were companies/business and business associations - proposed the EU to employ mechanisms such as regulatory sandboxes before introducing new regulations in order to ensure that future legislation is fit for purpose, innovation-friendly, risk-based and future-proof. Similarly, 10% of the respondents (17 of 167) suggested that ensuring a proper registration, protection, and enforcement of trademarks, designs, and other intellectual property rights was crucial in virtual worlds to protect consumers and uphold the EU's IP system. In addition, 14% of respondents (24 of 167) many of them from the creative sector, mentioned that copyright protection in virtual worlds is essential to ensure the sustainability of the EU cultural and creative sectors and indicated that the existing copyright framework should apply to platforms, and services operating on those platforms, to protect creators' rights. In the case of non-fungible tokens (NFTs), although they are in general seen as opportunities for new, fairer business models by respondents (18%- 11 of 167), there is a need for more understanding of use cases and application of NFTs and to clarify regulations that apply to crypto assets.

Secure and sustainable digital infrastructures

24 respondents (14% - 24 of 167), mostly from Business/Associations and companies/business, commented on the necessity of fulfilling the new network capabilities and features required for virtual worlds, this meaning managing an increasing data traffic as well as evolving requirements e.g., on latency and bandwidth. Large telecom companies are convinced that connectivity and digital infrastructure are key enablers for Europe to take a leading role in the development of virtual worlds. Other companies/business also consider that there should be more favourable market conditions for telecommunication companies. Although digital infrastructures are critical for the development of virtual

worlds and Web4.0, this initiative does not address the topic as it is covered by a parallel strand, the EC's connectivity package.

Digitalisation of public services (government)

19 respondents (12%- 19 of 167) believe that public administrations and bodies can significantly contribute to driving innovation in virtual worlds and Web 4.0 by establishing frameworks and infrastructures to facilitate further development and adoption of the technology.

Some respondents (4% - 6 of 167) highlighted the need for partnerships between the public and the private sector to spur investment, innovation and growth in the EU economy. Similarly, another 8% of respondents (13 of 167) mentioned that it is important for EU Member States to establish coordinated national strategies to create attractive, innovation-oriented environments for entrepreneurs and businesses.

**Digital Rights and Principles**

People at the centre

A 22% of respondents (37 of 167) think that people should be at the centre of the digital transformation. Virtual worlds and Web4.0 technologies should serve and benefit all Europeans and empower them to pursue their aspirations, in full security and respect of their fundamental rights. Respondents considered that EU values and rights of individuals should be respected online as well as offline

Freedom of choice

Further to ensuring freedom of choice and fair virtual worlds, 51% of the respondents (86 of 167)- mostly from Business Associations, Companies/Business and NGOs, emphasised the importance of developing harmonised rules, protocols, and standards (57%- 34 of 167) in collaboration with like-minded international partners and organizations to ensure the interoperability (35%- 58 of 167) of virtual worlds not only in the EU but also at global level. Regarding the topic of empowering people while protecting them against risks and harm to their health and fundamental rights, some respondents expressed their concerns over the physiological consequences of the use of virtual worlds (specially on the well-being of minors) and the use of their biometric data.

Safety and security

More than half of the respondents in all categories (60% -100 of 167) consider that virtual worlds should be safe and secure, with a special attention in the protection of children and young people (11%- 19 of 167). This includes data protection (GDPR) and the right to privacy in virtual worlds, which is essential for 44% of the respondents (74 of 167), especially for Business associations, NGOs, companies/business and organisations. Furthermore,7% of respondents (12 of 167) consider that the Commission should mitigate risks of harassment, cyberbullying and hate speech in virtual worlds.

Solidarity and inclusion

All categories of respondents believed that virtual worlds should be inclusive and accessible (27%- 45 of 167). The respondents urged the Commission to develop comprehensive and inclusive policies for the development of virtual worlds. Some respondents suggested the revision of the European Accessibility Act (as it does not directly target virtual worlds technologies) to ensure virtual worlds are accessible and inclusive for people with disabilities from the outset. Other respondents focused on the inclusive access to the technology and the education needed.

Participation

26 respondents (16% -26 of 167) expressed their views regarding virtual worlds to be used as a tool for engaging citizens in the democratic process and fostering their participation in the public space. There is a division between those who thought that virtual worlds can help engage with citizens and civil society and increase citizens participation in the public space, and those who had concerns that increasing risks of disinformation and manipulation (19%- 17 of 167) could potentially impact democracy and social cohesion in a negative way.

Sustainability

Concerning sustainability and the green transition, 33 respondents (20% - 33 of 167) consider crucial to promote sustainability in the development of virtual worlds and Web4.0. While some respondents express their concerns about energy consumption and environmental impact, others such as large companies/businesses consider that industrial virtual worlds can help to solve real problems and enable more intelligent, intuitive design and manufacturing processes, and to make buildings and cities, grids and transportation systems more efficient and sustainable. In addition, those respondents consider that virtual worlds can also contribute to minimise the environmental footprint of the clothes and tourism sectors and to improve business competitiveness by saving costs as well as increasing efficiency and productivity.

# ANNEX 3: FACTUAL REPORT ON THE "SAFER INTERNET DAY" WORKSHOP

## 2023 SAFER INTERNET DAY

**Disclaimer: This document should be regarded solely as a summary of the feedback and impressions collected during an event organised by DG Connect with a class of high-school pupils. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

BACKGROUND

The updated Better internet for kids (BIK+) strategy is the digital arm of the EU Strategy on the rights of the child which ensures a comprehensive and inter-related approach to childrens' rights. The BIK+ lays down the European Commission's commitment to consult kids on key EU policies. In this context, to celebrate the 20th edition of Safer Internet Day and to include views from children in the preparatory work for the Communication on virtual words, a special event was held in Luxembourg on February 10th, 2023.

METHODOLOGY

The focus group exercise was aimed at collecting the views of individual citizens under 18 years of age. A class of 21 high-school students (9 girls and 12 boys), in a Luxembourgish state school with both local and international pupils, was provided with an opportunity to engage with virtual and augmented reality technologies and share their opinions on the experience. The session's introduction focused on EU policies on digital and virtual worlds and internet safety, accompanied by a series of survey polls via Slido. After a short theoretical session, the participants had then the possibility to test five virtual reality activities and one augmented reality app.

At the end of each virtual experience, the kids were invited to take written note of their impressions. Once the round of all the virtual experiences was concluded, the pupils formed 3 discussion groups, each one focusing on the following question:

- How do you feel about virtual worlds, now you have experienced them?
- What would you use virtual worlds for?
- What do adults not understand about the virtual world?

CONCLUSIONS

The participants engaged actively and provided valuable input throughout the event. The results of the polls and discussions shed a light on their familiarity with the virtual worlds and on their present and future role in the education and professional life of young people. It appears that 77% of the surveyed group play video games regularly and are familiar with the virtual worlds. When asked about the future, 55% of the respondents did not believe that virtual worlds would become parallel realities to the physical world, and none of them considered that VR would be used in their future jobs. At the same time, only a third (29%) expressed a desire to receive a VR headset as a gift.

The conclusions and reflections of the focus group discussion pointed to opportunities rather than risks. The participants specified that using virtual and augmented reality as immersive learning tools could be a powerful teaching aid (77%), especially in areas such as art, biology, physics or history. The vast array of VR applications and their versatility could revolutionise how education is imparted, leading to improved learning outcomes. Despite an enthusiastic evaluation of the exercise (100% satisfaction rate), the pupils consulted would like to have their classes delivered via VR only occasionally (48%), in combination with traditional classroom teaching.

Nowadays kids are considered the first generation 'growing up' in virtual worlds. The young users in question presented a rather intuitive approach as far as their ability to navigate the experiences was concerned. Among the proposed VR experiences, the one dedicated to exploring the International Space Station was found to be the most difficult to use (48%), while the National Geographic experience was the most popular (52%). As a young technology there are still many unknowns about the long-term risks and effects of VR; during the exercise most participants did not report any motion sickness, however, a few indicated short-term dizziness after wearing the headsets for a short time (maximum length of each experience was 5 minutes).

It was emphasised that technology continues to create significant changes in social and cultural practices and could increase the generational divides. While the VR experience offered to the 15-year-olds was unanimously appreciated by all participants, the young people nevertheless underlined that "we shouldn't get detached from the real world".

# ANNEX 4: FACTUAL REPORT ON THE CODE WEEK WORKSHOP

**Disclaimer: The views presented in this factual summary report are not the views of the European Commission but of the stakeholders who participated in the consultation. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

BACKGROUND

This workshop with code week stakeholders was part of the consultation with representatives from various areas of research, industry, civil society in the context of the EU initiative on virtual worlds. It followed the Code Week event that took place in Brussels ten days before.

METHODOLOGY

Invitations were sent to CodeWeek stakeholders for a two-hour discussion on virtual worlds focusing on education and skills needs.

The event was held online on the 28th of March 2023. The EC started with an introduction of the topic and elaborated on the main EC activities, policy and research wise, regarding virtual worlds. The presentation was followed by a discussion around the following set of questions:

a. You are in regular and close contacts with young kids. ´Virtual worlds will most probably deeply transform their lives, privately and professionally, in the next decade. Do you think they are aware of this coming revolution, ready for it and how can we make sure they are well prepared for this?
b. What are the basic skills that each student (and future citizen) will need to thrive in virtual worlds and virtual worlds?
c. As Codeweek stakeholders, what are to your opinion virtual worlds use cases or applications you think might be useful in your line of work?

The workshop was moderated and concluded by the EC with main take-away messages.

The participants included 12 externals: 7 Ambassadors (R&D, academic, pedagogical staff from Denmark, Finland, Ireland, Latvia, Poland, Portugal, Slovenia) and 5 Edu coordinators (administrative persons in ministries of Education from Belgium, Croatia, Hungary, Serbia and Slovenia) and EC representatives (Deputy Head of Unit and colleagues from the interactive technologies and digital education teams).

CONCLUSIONS

The stakeholders participated actively to the discussions and were interested in sharing with us their experience, opinions and recommendations.

They brought into attention several aspects that need to be taken into consideration regarding the development and use of virtual worlds, especially related to the education domain.

- Kids are already using platforms such as Roblox for playing games, so they are already exposed to such technology. However, they are not aware of the ethical aspects, do not know how to protect themselves. There should be a control of kids under a certain age on which technology they are using. Moreover, kids may start feeling sick/dizzy after using VR equipment for a certain amount of time.
- Regarding needed skills it was mentioned that it is important to identify/see the reasons why we want students to use virtual worlds. Do we want them to use virtual worlds just for entertainment/education or do we want them to understand how they are created. A new layer of abstraction comes up with every new technology.
- Skills are important for both teachers (upskilling) and students.
- But also, specialists working in the field need skills: in plus of good coding skills, developers need also more specific XR skills.
- Standards are necessary to facilitate teachers and students the integration and assembling of readymade blocks to create immersive experiences/environments.
- Accessibility should be for everyone: some schools are more advanced in technology equipment than others which creates gaps and all kids, irrespective of their abilities should be given the opportunity to use such technologies. Here it was given the example of a Polish government program for virtual experiences for kids with disabilities.
- Online safety and data protection were presented as key values. It was discussed the issue of how much of ourselves do we want to reveal in an avatar and that safety should be embedded from the developing stage. As for data protection, technologies used for capturing information, such as eye-tracking were mentioned as possibly dangerous as they reveal sensitive information on personal data.
- Teachers and educators should be provided with guidelines, short and clear like for dummies (maybe as part of code week event), but also peer to peer learning and mentorship are very important.
- Some participants expressed doubts on the materialisation of certain estimates regarding the high figures for market and usage of virtual worlds in the near future while others were more optimistic in this respect.

# ANNEX 5: FACTUAL REPORT ON THE "INDUSTRIAL METAVERSE" WORKSHOP

**Disclaimer: The views presented in this factual summary report are not the views of the European Commission but of the stakeholders who participated in the workshop. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

## BACKGROUND

On 16 February 2023, DG GROW G3 co-organised with the European Round Table for Industry (ERT) a workshop on the industrial metaverse. The purpose of the workshop was to better understand the concept of 'industrial metaverse' and its use cases, its relevance to European industry, uptake challenges and enabling factors, as well as the strengths, weaknesses, and dependencies of European companies. Additionally, industrial players identified areas in which the Commission could support the emerging ecosystem on a macro level. The workshop drew significant participation, with over 70 participants, including DG and DG CNECT staff.

## METHODOLOGY

The industrial metaverse largely builds on the digital twin: it is a place to experience the digital twin of industrial assets in an immersive environment, to meet in real time to review it collaboratively and make changes immediately, to interactively evaluate and simulate its behaviour and to managing real assets in closed loop. While it relies mostly on the same technologies as other metaverse segments – such as gaming-oriented metaverses, enterprise metaverses, or consumer-oriented ones - it is characterized with different leading providers, different challenges and with a different value proposition for its industrial consumers.

The workshop explored these specific characteristics with five use cases focusing on its implementation in manufacturing, product development, retail and the green transition. Attendees were presented with examples of the tangible benefits that early adopters of this technology have experienced, such as faster development, reduced production time, higher product quality, fewer emissions and less waste. For instance, a use case on green transition highlighted how the metaverse can accelerate the scale-up of green hydrogen production on an industrial scale.

Participants also explored Europe's strengths and opportunities: when it comes to cloud, security, software provision and XR hardware manufacturing, Europe is falling behind other regions, yet it holds a strong position in research, design, network technologies, 5G, operations, blockchain and Web 3.0. A low business awareness and a slow technology uptake were identified as the main weaknesses compared to other regions. The skills-gap for the metaverse is growing, although there is currently a relatively low shortage of skilled professionals.

## CONCLUSIONS

- **Need for a strong, industry-led standardisation**: The metaverse is a combination of different technologies, and there are also emerging technologies that can potentially contribute to the development of the metaverse. The Metaverse Standards Forum has been established with the participation of many industrial players to coordinate the standardisation of these various underlying technologies. A strong European industrial

representation will help secure a European leadership in the industrial metaverse ecosystem.

- **Focus on the industrial metaverse**: The specific challenges and characteristics of the industrial metaverse should be tackled in parallel with the ongoing dialog around the consumer metaverse.
- **Need to strengthen links with EU research and academia**: Collaboration between the industrial sector and research institutions needs to be reinforced.
- **Shortage of skilled experts**: There is a growing shortage of skilled professionals in the sector, which requires support for the training of the next generation of designers and VR experts.
- **Next-generation connectivity is crucial**: The future of the industrial metaverse relies heavily on next-generation connectivity, including future spectrum allocation and licensing spans.
- **Support for an enabling Intellectual Property and cybersecurity framework**: An appropriate framework for IP protection and cybersecurity is crucial for the success of the industrial metaverse.
- **Slow uptake of digital technologies by European companies & insufficient awareness of the potential brought by the industrial metaverse**: The low adoption of digital technologies by European companies is a significant barrier to the success of the industrial metaverse. Enabling technologies, such as Digital Twins, Cloud, 5G, 6G Blockchain (NFTs), AI, AR/VR, need further support both from the public and the private sector, as well as more awareness raising about the industrial metaverse' potential benefits for industry.
- **Wide collaboration among industrial players**, including non-European companies is key: Interoperability is essential to foster cross-company exchanges, requiring extensive collaboration among industrial players, including non-European companies.
- **Access to finance** regime in Europe support public investment into new technologies. Horizon Europe mentioned as potential financing vehicle to support industrial metaverse development

# ANNEX 6: SYNOPSIS REPORT ON THE STAKEHOLDER'S CONSULTATIONS

**Disclaimer: The views presented in this synopsis report are not the views of the European Commission but of the stakeholders who participated in the workshop. It cannot in any circumstances be regarded as the official position of the Commission or its services.**

This synopsis report of the stakeholders' consultations on virtual worlds provides an overview of all the consultations the European Commission (EC) conducted throughout the 1st and 2nd quarters of 2023. The report also summarises and analyses the main outcomes of the consultation activities.

The overall consultation exercise targeted a broad range of stakeholders according to their interest and expertise in the subject of virtual worlds and Web4.0. These included individuals, citizens, research and academia, businesses (large-size and SMEs, microenterprises, self-companies, consulting firms), businesses associations, public authorities (Member States, regional and local public authorities, international organisations), standardisation bodies, non-governmental organisations and social partners and representatives of professions and crafts (Chambers of Commerce, Trade Unions and other profession representatives).

The consultation took as a premise the development of virtual worlds and Web4.0 with a view of ensuring the respect of EU values and compliance with EU regulations. The vision for openness, safety and respect was in line with the Digital Decade policy programme[210] that, together with the European Declaration on Digital Rights and Principles[211], sets the path towards a human-centred, sustainable and prosperous digital future. The objective of these consultations was to capture the stakeholders' views to allow the EC to shape up an informed strategy, with pertinent actions, able to reflect a shared vision on how the virtual worlds should be built and developed in the future.

Given the multitude of aspects encompassed by the initiative, the large-scale consultations that the EC conducted took place at EU-level, involving a variety of stakeholders who discussed issues covering a broad scope of sectors, as it will be shown in detail further below.

It is to be noted that the consultation on the topic of connectivity infrastructures, a critical area for the development of virtual worlds and Web 4.0, is not part of the initiative on virtual worlds, but is covered by a parallel strand by the EC's connectivity package[212], including the Gigabit Infrastructure Act.

## Consultation activities – context, stakeholders and methodology

The stakeholder consultations were conducted in three ways:

- European Citizens' Virtual Worlds Panel

[210] DECISION (EU) 2022/2481
[211] COM(2022) 28 final
[212] https://digital-strategy.ec.europa.eu/en/policies/eu-rules-reduce-cost-high-speed-broadband-deployment

- Targeted Consultations
- Call for Evidence

In addition to the information contained in this Section 3.3, more details of each of the consultations can be found in the respective factual reports annexed to this staff working document: Annex 1 (Stakeholder Workshop Consultations), Annex 2 (Call for Evidence), Annex 3 (Safer internet day Workshop), Annex 4 (Code Week Workshop), Annex 5 (Industrial Metaverse Workshop).

*European Citizens' Virtual Worlds Panel*

The European Citizens' panel on virtual worlds is one of three citizens' panels organised by the European Commission to deliver on the commitment expressed by Communication (of 17 June 2022) "Putting Vision into Concrete Action" [213] and by President von der Leyen during the 2022 State of the Union.

A total of 149 randomly selected citizens from all 27 Member States took part in three sessions over three weekends between February 2023 and April 2023 deliberating on the question: What vision, principles, and actions should guide the development of desirable and fair virtual worlds?

They were tasked with developing a set of guiding principles and actions for the development of virtual worlds in the EU. In the final session, the citizens formulated a set of recommendations with the aim to ensure that virtual worlds in the EU are fair and relevant to citizens**,** based on the principles and actions that they had developed during the previous sessions.

The result was 23 recommendations that were approved by all the citizens in the panel[214]

*Targeted Consultations*

The targeted consultations consisted of five workshops on virtual worlds dedicated to supporting the initiative on virtual worlds and three additional events which included this subject on their agenda. They all took place between January and March 2023.

The five workshops focused on collecting opinions from stakeholders coming from different European industry sectors, universities and research centres, the VR/AR Industrial Coalition[215] and virtual worlds related associations. They took place online on 25 January, 8 and 15 February, 2 and 6 March 2023, and the attendance was based on individual invitation.

Overall, the targeted stakeholders for these events were selected from categories representing:

[213] COM/2022/404 final
[214] https://citizens.ec.europa.eu/virtual-worlds-panel_en
[215] https://digital-strategy.ec.europa.eu/en/policies/virtual-and-augmented-reality-coalition

- European companies having taken up innovative technologies for running their activities in branches such as Culture and Creative Industries (CCI), education, media, aerospace, tourism, construction, automotive.
- Developers and providers of innovative technologies relevant for virtual worlds in the EU (e.g., 3D, headsets manufacturing, XR, digital twins, telecommunications)
- University and research centres/ laboratories in the EU with teaching curricula and/or projects on subjects related to virtual worlds
- VR/AR Industrial Coalition associate and associations related to virtual worlds.

Harvesting feedback from the interaction of participants with such diverse profiles, i.e., end-users, tech developers, academics, researchers, and stakeholders associated to the European VR/AR ecosystem, led to rich multifaceted results, matching the complexity of the subject matter.

Additional consultations:

- 2023 Safer Internet Day[216]

In compliance with the Better Internet for Kids (BIK+) strategy[217], the EC consults children on key EU policies. Gathered to celebrate the 20th edition of Safer Internet Day on 10 February 2023, a group of Luxembourgish high-school students engaged in a few VR and AR experiences and shared their opinions about virtual worlds.

- Code Week Workshop

As an extension of the planned EU Code Week[218] activities, on 28 March 2023, 12 Code Week stakeholders (teachers, academia lecturers, education coordinators) from 12 European countries were invited by the EC staff to have a discussion on virtual worlds, with a focus on education and skills needs.

- Industrial Virtual Worlds Workshop

Several EC services had the opportunity to meet on 16 February 2023 with members of the European Round Table for Industry (ERT)[219] in a workshop organised by DG GROW dedicated to the industrial virtual worlds. The purpose of the workshop was to better understand the concept of 'industrial virtual worlds and its use cases, its relevance to European industry, uptake challenges and enabling factors, as well as the strengths, weaknesses, and dependencies of European companies.

*Call for evidence*

A call for evidence to gather stakeholder's views took the form of a public consultation that ran from 5 April to 3 May 2023 on the Commission's "Have your say" portal and was available in the 24 EU languages. This online consultation aimed at collecting the views on the development of virtual worlds and Web 4.0 from a broad spectrum of stakeholders:

216 https://digital-strategy.ec.europa.eu/en/policies/safer-internet-day
217 https://digital-strategy.ec.europa.eu/en/policies/strategy-better-internet-kids
218 https://codeweek.eu/
219 https://ert.eu/

individuals, public authorities, businesses, research and academia, standardisation bodies, NGOs, representatives of professions.

Out of the total of 167 respondents contributed to the public consultation. The highest rates came from the following categories: EU citizens, with 42 responses (25,15%), business associations with 31 responses (18,56%), companies/businesses with 30 responses (17,96%) and NGOs with 24 responses (14,37%).

**Summary of consultations results**

The three types of consultations (i.e., Citizen's Panel, targeted workshops and online call for evidence) enabled EC services to collect a wealth of opinions shared by stakeholders coming from diverse social and professional backgrounds and geographical areas within EU and outside the EU (in the case of the call for evidence). The views of the different stakeholders were discussed and recorded during the workshops, expressed in writing through the call for evidence, or directly converted into recommendations in the case of the Citizens' Panel exercise. While focussing on the identification of opportunities and challenges of the virtual worlds, each type of consultation followed different methodologies, which meant the feedback was structured differently.

The Digital Decade policy programme[220] is a key point of reference for setting the path towards a human-centred, sustainable and prosperous digital future, including virtual worlds and Web 4.0. Because of that, the main opinions emerging from the consultations are clustered below around two main categories: the cardinal points of the Digital Compass and the principles of the Declaration on Digital Rights and principles; and are presented in the form of recommendations from the stakeholders.

- Cluster 1- Digital Compass cardinal points: skills, business, infrastructure, government,
- Cluster 2 – Digital Rights and Principles: People at the centre, Freedom of choice, Safety and security, Solidarity and inclusion, Participation, Sustainability

*Cluster 1: Digital Decade Compass cardinal points*

*Businesses*

- **Support for the uptake of new technologies**. The consultations highlighted that digital technologies are taken up at a slow pace by EU companies. For the adoption of enabling technologies, such as Digital Twins, Cloud, 5G, 6G Blockchain (NFTs), AI, AR/VR, the companies need access to finance from both the public and the private sectors. Another factor that could help with accelerating the process is **awareness raising** on the potential benefits of the virtual worlds (e.g., improvement of processes, cost saving, increase in productivity).

[220] DECISION (EU) 2022/2481

- **Support for research, development and deployment of technologies** underlying virtual-worlds and Web 4.0 through EU funding programs. This is especially important in relation to industrial scenarios, which have the potential to drive significant economic growth and job creation.
- **An EU ecosystem for all players in the virtual worlds**. Collaboration among all industrial players should be encouraged, for example by creating opportunities to share knowledge and best practices. Collaboration between the industrial sector and research institutions needs to be reinforced, as well.
- **Standardisation**. The consultations pointed out that EU should takes steps in putting in place a strong industry-led standardisation system focussed on interoperability. It is necessary to provide standards and open protocols for the European players, (SMEs, research labs, entrepreneurs), and beyond internationally, in software and hardware development, 3D modelling, and digital identity. Industry stakeholders mentioned other potential standardisation needs such as developing accounting standards for valuation of virtual assets or setting up a permanent body to promote quality standards and provide advice and resources to national policy makers and organisations.
- **EU technological autonomy.** Respondents suggested to put in place measures to reduce the dependence on US and Asian hardware and to build an EU platform for virtual worlds.

*Infrastructures*

- **Digital infrastructure development.** In the citizens' viewpoint, a far-reaching infrastructural development plan should be implemented made to ensure equal and affordable access to digital technologies, through the implementation of a far-reaching infrastructural development plan. This plan should focus on affordable, financeable accessible developments for everyone. On the industry side, stakeholders underlined that the future of the industrial virtual worlds relies heavily on next-generation connectivity, including future spectrum allocation and licensing spans. They recommended that the EC assists the Member States in agreeing on common solutions for infrastructure. In the call for evidence, stakeholders stressed the necessity of fulfilling the new network capabilities and features required for virtual worlds, i.e., this meaning managing an increasing data traffic as well as evolving requirements e.g., on latency and bandwidth.

*Government*

- **Innovation-oriented policymaking.** Member States (MS) governments and EU legislators should cultivate a forward-looking attitude to integrate innovation in their policies. Innovation from industry and academia should be streamlined for having a more holistic approach, while synergies between related services, developments and related funding are fully exploited.
- **Open data**. Public bodies should make available open data to be used for the development of innovative applications for virtual worlds.

- **Regular review of existing relevant EU guidelines**. EU guidelines on ethical and technological standards should be regularly reviewed and updated to fit to the virtual worlds.

*Skills*

- **Skills for job finding in virtual worlds.** Virtual spaces entail the opening of a new economy of services and the creation of new and more inclusive opportunities, and the need for protection by the EU legislation. Young people, but also disabled persons, might be able to find jobs in different work areas and feel included. In the citizen panel and the call for evidence, stakeholders strongly voiced the idea that essential training, reskilling and upskilling, accessible to everyone wishing to work in virtual worlds, should be granted within a harmonised EU framework to allow for a certification recognised in all Member States.
- **Education and literacy.** These were recurrent topics throughout the consultations. Academia representatives pointed out that, from a teaching perspective, virtual worlds allow students and learners to better visualise complex and abstract notions, allow a higher degree of interaction and engagement, and improve memory retention. The children consulted recognised that immersive tools could enhance learning and improve learning outcomes. To be able to attain these results, it is imperative, in the citizens' opinion, that teachers and educators in the EU be aware of opportunities and risks of immersive environments and receive appropriate training to master digital tools.
- **Shortage of skilled professionals.** The lack of adequate skills in the enabling technologies may in part be responsible for the slow adoption of innovative technologies by the enterprises. Training the next generation of designers and VR experts, encouraging multidisciplinary skill sets and nurturing and supporting talent. Stakeholders representing businesses also emphasised in the workshops and the call for evidence the need to address the increasing scarcity of skilled professionals.
- **Awareness raising**. Industry representatives stressed that the general public, business leaders and other players should be aware of the multiplicity of virtual worlds (e.g., social, industrial), and understand the technology behind products presented in these environments.
- **Empowerment.** The citizens emphasised the need for EU guidelines to navigate through the virtual worlds, i.e., to understand what they are about, provide the right information on good usage and risks, etc. Moreover, indicators that can measure the social, environmental, mental and physical health impacts would be particularly useful in identifying potential threats and maintain healthy, inclusive, transparent and sustainable virtual worlds.
- **Better access to media and cultural experiences.** The virtual worlds can boost creativity and provide new ways of storytelling in diverse languages, thus reaching out to new and more inclusive audiences. EU cultural heritage, for example,

becomes more accessible to young people, according to the some of the consulted stakeholders.

*Cluster 2: Digital Rights and Principles*

*People at the centre* (Technological development and regulation of virtual worlds are serving and respecting the needs, rights and expectations of users)

- **Participatory design.** Users get involved in the creation of tools and applications for virtual worlds so that their needs should be better met.
- **Health concerns** potentially deriving from the use of virtual worlds, especially for young people should be measured and addressed by the EC, as shown by the results of the citizen panel and call for evidence consultations.

*Freedom of choice* (The use of virtual worlds is a free choice for individuals – without disadvantages for those who are not participating.)

- **Digital identity in the virtual worlds.** The citizens expressed the view that anonymity rights and authentication obligations should be regulated at EU level. This would give a sense of security. Industry representatives argued that, based on healthy commercial values and a well-designed digital identity system, companies and users could collaborate better. Fakes and fraud might also be avoided.

*Safety and security* (European citizens need to be kept safe and secure, including the protection of data and preventing manipulation and theft)

- **Personal data.** Companies should be transparent about the usage and guarantee the security of personal data.
- **Company and user certification for the virtual worlds.** The citizens have proposed the issuing of common standards-based certificates for the different usages of the virtual worlds.
- **Protection of children and young people** should be in focus, as pointed out by respondents in the call for evidence.
- **Mitigation of risks** of disinformation, manipulation, cyberbullying and hate speech in virtual worlds. These risks need to be tackled by the EC, according to multiple stakeholders in the call for evidence. There was a suggestion to issue a recommendation to fight against harmful content, fakes and disinformation by labelling AI in virtual worlds.

*Solidarity and inclusion* (Society members share fairly benefits and obligations; Equal accessibility for all citizens is granted – regardless of age, income, skills, technological availability, country, etc.).

- **Sharing knowledge.** Particularly relevant for industries, stakeholders stressed the importance of sharing guidelines and best practices based on an EU common vision on virtual worlds (e.g., in an open-source library). Moreover, it could be useful to share results from EU and national funded projects. Industry stakeholders also expressed the wish to have a platform that serves as a marketplace for ongoing initiatives and new technologies relevant for virtual worlds.

- **Partnerships and collaborations**. Apart from networking and shared projects, collaboration in initiatives such as local pilot projects (e.g., group of people with specific needs) or living labs in different areas may have a real impact.
- **Inclusion**. Citizens put forward the recommendation for legislation in favour of work-life balance, and of citizen inclusion (i.e., disabled persons, digital illiterate people). On the other hand, the respondents in the call for evidence urged the EC to develop comprehensive and inclusive policies for the development of virtual worlds. Some respondents suggested the revision of the European Accessibility Act (as it does not directly target virtual worlds technologies) to ensure virtual worlds are accessible and inclusive for people with disabilities from the outset.

*Participation* (The users are actively and equally involved in the design, running and development of virtual worlds.)

- **Close collaboration between players in the regulatory and standard-setting processes, under EC lead.** Researchers, industry, legislators, social partners, officials, as well as users should join participatory forums and platforms to work together to develop and regulate virtual worlds. This would ensure the fairness and transparency of the processes.

*Sustainability* (The set-up and use of virtual worlds is environmental-friendly.)

- **UN's Sustainable Development Goals (SDGs).** Virtual worlds should be built with the 17 SDGs embedded in them.
- **Environmentally friendliness and sustainability.** Companies building virtual worlds should make sure that energy efficiency requirements are complied with. The impact on environment should be always measured (e.g., following the increase in server capacity). The citizens proposed that, at EU level, instruments should be put in place to have the equipment related to virtual worlds included in the circular economy. In addition, citizens and industries should be made aware of the overall environmental footprint of the use of virtual worlds.

**Analysis of the conclusions**

The subject of virtual worlds and Web 4.0 raised a lot of interest among people, citizens, companies, researchers, academia and representatives of diverse socio-professional categories from all corners of the EU. Intense debates and extensive contributions focussed on the multiple facets and implications of the virtual worlds phenomenon which is finding itself an increasingly larger place in the real life, be it at private, work or community level.

The EC carefully analysed and compared the recommendations surfacing from the three types of consultations that it carried out. The most important takeaway is that stakeholders almost unanimously expect to see the EC take the initiative and propose actions at EU level. This proof of trust in the EC's capacity to promote prosperity and protect citizens provides a solid foundation for the proposed measures on virtual worlds and Web 4.0.

The analysis of the consultations results revealed many converging opinions, based on which the EC could formulate clear lines of strategies and concrete actions. Nevertheless,

it was also noted that, according to the stakeholders' profiles, the feedback naturally tended to make certain aspects more prominent than others. For example, the citizen panel outlined concerns related to privacy, equality, skills, while the discussions with industries representatives brought forward issues such as standardisation, uptake of innovative technologies, and developing further and consolidating an EU industrial ecosystem on virtual worlds and Web4.0.