LSE Consulting

LSE Policy Brief

Unleashing European Innovations for the Metaverse

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Disclaimer

This document is authored by LSE Consulting with collected inputs, comments and feedback from BMW Group, Bosch Sensortec, Ericsson, EssilorLuxottica, IKEA Retail (Ingka Group), Lufthansa, Meta and a workshop organised in October 2023 with CEA Leti, EPIC, Ericsson, EssilorLuxottica, Fraunhofer ENAS, IMEC, Lam Research, Meta, MICLEDI Microdisplays, Osram, STMicroelectronics, Synopsys, TriLite, and Tyndall. However, this report does not represent the views or positions of any individual organisation or individual mentioned in this document other than its authors.

Foreword

Europe may rank at the top of various metrics on sustainability, inclusion, and social progress, but an increasing number of voices across Europe are relaying concerns about the region's economic competitiveness. While it is still one of the world's largest economies, Europe's relative position is slipping. Although the EU accounted for nearly a quarter of the world's GDP in 1990 (on PPP basis, unadjusted for Brexit), it has now reached 14%. Moreover, in 2022, the US had a net inflow of foreign direct investments (FDI) that was almost three times higher than the EU, even with intra-union flows included (World Bank). These developments are not lost on the von der Leyen Commission, with "competitiveness" mentioned multiple times throughout the last State of the Union address, and with good reason.

As we stand on the cusp of the next evolution of the internet, Europe has a unique opportunity to change its trajectory and curb these trends. Emerging technologies like artificial intelligence and metaverse technologies can potentially boost European productivity if the incoming European Commission and Parliament seize the opportunity and begin to lay suitable foundations. Recent papers indicate that the metaverse could have substantial upside potential for the EU economy. How Europe manages its adoption when completing the digital single market will determine whether Europe will successfully digitise and revitalise its industries and whether European businesses can compete and thrive globally.

While there seems to be an AI awakening among European leaders, the metaverse and immersive technologies do not get the same attention. Nevertheless, European companies are already exploring some of the most innovative uses of the metaverse and immersive technologies in every aspect of our society. Thanks to digital twinning and other industrial applications, the pace at which we embrace this transformation will greatly affect our productivity. Similarly, augmented reality devices natively embed generative AI technologies, such as AI assistants, creating new opportunities for consumers and businesses. In other words, an immersive internet could have a more profound impact on European competitiveness than it has in the past. But without an ambitious industrial vision, Europe may lose the internet race resulting in dire economic consequences.

We – the leading industry and technology firms behind many of these exciting use cases – have provided inputs to this study and its exploration of the role played by European R&D in this transformative journey. While no report may capture the full diversity of our collective views, its conclusions are an insightful testament to Europe's burgeoning potential in the metaverse.

The study argues for the creation of a pan-European industrial cluster for immersive technologies – an "Airbus" for the metaverse – backed by long-term funding to tackle the innovation challenge and to foster integration and manufacturing of immersive technologies in Europe. Equally important is the focus on nurturing a talent pool for research and commercialisation. This conclusion resonates deeply with our commitment to conducting R&D in Europe and contributing to upskilling its workforce.

Moreover, the report underscores a market reality that calls for an open and scalable ecosystem. The recommendations to promote standardisation, connectivity, European content, and wider use in public education reflect a critical understanding of the demand-side equation.

This study resonates with our aspirations for a Europe at the forefront of metaverse development. It charts a course towards innovation leadership that we hope will inspire national governments and European institutions into action.

The future of the internet can be made here in Europe – if only we dare embrace it.

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Introduction

Building the Internet's future in Europe

Since the term "metaverse" appeared in print for the first time through fiction in 1992,[1] many definitions have flourished in scientific and interdisciplinary research.[2] In its essence, the metaverse consists of immersive and virtual environments where physical and digital worlds seamlessly converge, and users share immersive experiences in three dimensions (3D). The metaverse forms a **digital-physical continuum** that reimagines how we perceive space.

While the term is also sometimes used interchangeably with "immersive technologies", the latter refers to several technologies that enhance users' presence in the metaverse. These include extended reality (XR), which encompasses virtual and mixed reality (VR and MR), artificial intelligence (AI), the Internet of Things (IoT). The metaverse will also require multiple connectivity networks like 5G/6G, Wifi and Bluetooth – and in particular, 5G/6G will be used for mobility use cases, and WiFi and Bluetooth for personal area use cases. The metaverse and its associated immersive technologies are a key pillar of the impending fourth generation of the web (**Web 4.0**).

The metaverse is likely to evolve incrementally over time, similar to previous evolutions of the internet. But there is already an assumption among European policymakers that the next iteration of the web will revolve around fully immersive experiences.[3] In its 2023 strategic communication, the EU recognises that the metaverse and virtual worlds are "now technically and economically feasible thanks to rapid technological advances and an improved connectivity infrastructure".[4]

Despite these developments, research highlights low adoption rates and a general lack of awareness and prioritisation of metaverse technologies amongst European firms. Therefore, this policy brief aims to identify **innovation policy** recommendations to unleash the potential of the metaverse in Europe. In particular, measures to improve research, industry growth and talent development are explored. And the metaverse will also change how we interact with the Internet and must be grounded in **human-centric** dimensions of safety, sustainability, inclusion, diversity, and well-being.

This paper begins with a review of metaverse deployment. Drawing on existing literature and interviews with early adopters, macro and firm-level impacts are considered across a multitude of industrial sectors. The report then canvasses Europe's strengths and identifies potential impediments to deployment, discussed among European firms and research technology organisations (RTOs).[5] Based on identified gaps, the authors conclude with actionable policy recommendations on how Europe can develop innovation leadership.

[1] Stevenson, Snow Crash, 1992
[2] See inter alia Damar, 2021; Ritterbusch & Teichmann, 2023; Green & Works, 2022
[3] European Commission, 2023
[4] ibid.
[5] Inputs collected during a workshop with CEA Leti, EPIC, LM Ericsson, Essilor-Luxottica, Fraunhofer ENAS, IMEC, Lam Research, Meta, MICLEDI Microdisplays, Osram, STMicroelectronics, Synopsys, TriLite, and Tyndall.

Understanding the stakes

Macro and micro-level impacts of metaverse

The metaverse offers a range of existing and prospective use cases across the economy. It is the digital factory floor of the future, which can also deliver innovative and immersive customer experiences that enhance European brands. An estimate by Analysis Group shows that the metaverse could contribute as much as **€400 billion to European GDP** by 2031.[6] At the global level, various consultancy reports estimate that AR and VR applications have the potential to reach €766 billion in global turnover by 2025,[7] and up to €1.3 trillion by 2030.[8]

In particular, the metaverse is integral to the digital transformation of European industry. By combining the metaverse with other next-generation applications like AI, machine learning (ML), IoT, and automation, manufacturers are already unleashing the efficiency gains associated with smart factories and Industrie 4.0. This kind of interconnected and immersive production will be at the centre of **productivity growth** in advanced economies during the next decade and beyond.[9]

As a consequence of natural and technological factors, European productivity growth has been in long-term decline compared to other regions.[10] Thus, boosting relative **competitiveness** is a strong incentive for metaverse adoption. This conclusion is supported by a breadth of empirical research. Studies suggest that smart factory adopters enjoy increased labour productivity of up to 12%. Meanwhile, the implementation of "digital twins" – virtual models of the physical world for advanced analytics – can increase profit margins by 54%.[11]

With great technological potential comes significant **opportunity costs**. Partial equilibrium analysis shows that the loss of competitiveness associated with late adoption of the metaverse would lead to a 9.9 per cent decrease in EU auto exports, equating to an annual loss of €12.5 billion for the German auto industry alone.[12]

Aside from industrial competitiveness, metaverse and virtual worlds "bring unprecedented opportunities" in many **societal areas**. They can foster better health services, more engaging education and training, new forms of interaction and collaboration among people, and immersive cultural experiences.[13] In the EU policy context, the metaverse will also connect the physical Single Market with its much less integrated online equivalent, the Digital Single Market. Where the EU laws sometimes find it necessary to apply different rules for online and offline transactions, the metaverse – as an interconnected virtual market environment – could converge the online and offline iterations of the Single Market under the same rules. It could bring the physical consumer experience from one end of Europe to another with XR and AI-assisted translations.

Put simply, the metaverse extends beyond popular applications in gaming and remote working. Established research reveals a plethora of use cases across key verticals that drive advanced economies.

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[6] Analysis Group, 2022
[7] Market Research Future (2021), ARVR Market research report – Global forecast till 2027
[8] PwC (2019), Seeing is believing
[9] See Ar, Inklaar, McGuckin, 2003; Osterrieder, Budde, & Friedli, 2020
[10] See ECB Economic Bulletin, Issue 7/2021; nb the Economist, Productivity has grown faster in western Europe than in America, October 4, 2023
[11] Challenge Advisory, 2019
[12] Lee-Makiyama, Baker, 2024
[13] supra note 3

Some examples of some European use cases

In architecture, construction, and town planning, the metaverse allows for 3D models of buildings, streets, and entire cityscapes. This makes it easier to visualise and collaboratively adjust designs. According to a CGarchitect survey, several prominent architectural firms already use head-mounted displays (HMDs) for client presentations and concept formulations. Beyond product design and marketing, the metaverse can be used for project management and worker training by simulating virtual replicas of construction sites.

In education and training, lessons and content can be more engaging when delivered or demonstrated interactively in the metaverse. Research by PwC (2022) suggests that VR learners were trained four times faster in the classroom and were three times more confident applying skills learned from training. Copenhagen-based Labster, which sells virtual science laboratory simulations, already supports over three thousand schools and universities, and has raised over €130 million in venture capital funding (Labster, 2023).

In healthcare, academics have pointed to a metaverse of medical technology and AI (MeTAI) that can facilitate the development, prototyping, regulation, and refinement of AI-based medical practices, especially imaging-guided diagnosis and therapy. In Finland, Tampere University is leveraging VR, multi-sensory presentation, voice and gesture control, 3D printing, and haptic feedback to provide practitioners with new ways of interacting with large data masses like human tissue and its properties (Tampere University, 2019). These tools will expedite and improve diagnosis and treatment.

In manufacturing, firms are replicating physical factories, objects and facilities in the metaverse, and continuously updated with real-life IoT and systems data. The concept, called digital twinning, allows for virtual simulations to optimise performance and predict failures in complex systems. Auto manufacturers increasingly rely on 3D models to mitigate the transition costs to electric vehicle (EV) production.

In media, creative and cultural sectors, the metaverse provides a platform for creating and experiencing new forms of art and entertainment. Users can play immersive video games, attend virtual concerts and exhibits, and experience and participate in cultural events worldwide. Some of Europe's most famous cultural and artistic institutions now offer virtual tours, including The Louvre and The Guggenheim. Metaverse can also provide digital twins to preserve and restore heritage buildings (EU Web 4.0 Initiative, 2023).

In retail and marketing, the metaverse hosts cyber stores, personalised shopping experiences and new forms of brand engagement, including virtual events and avatar influencers. In addition to novel marketing opportunities, the metaverse offers scope for entirely new revenue streams via the sale of virtual goods and services.

The metaverse can also change how **public services** are provided. General administrative services can be provided in a more personalised manner, with remote assistance being especially beneficial in cases of remote or rural communities. It could also be useful with everyday public services such as traffic control, with real-time simulations helping optimise traffic flow and reduce emissions.

The metaverse can facilitate immersive interaction with **transport networks, logistics and supply chains** via digital twin systems in transport and logistics. The use revolutionises operations management by allowing suppliers and stakeholders to make highly informed real-time decisions.

CASE STUDY

BMW – Metaverse factory planning and vehicle development[14]

Case Overview

BMW Group is utilising metaverse technologies to plan and develop its upcoming electric vehicle plant in Debrecen, Hungary, scheduled to open in 2025. This marks BMW Group's first entirely virtual facility planning and validation in partnership with NVIDIA. The project adopts a digital-first strategy, employing NVIDIA Omniverse Enterprise, a platform for constructing and managing 3D industrial metaverse applications, to validate and optimise intricate manufacturing systems, including layouts, robotics, and logistics, through real-time digital twin simulations.

"From a BMW perspective, the metaverse is a virtual environment that utilises technologies like VR, AR, IoT, AI, and blockchain to enhance the entire automotive value chain. It enables immersive design experiences, seamless integration of physical and digital assets, and personalised interactions with customers."

Previously working across various tools with different levels of details and transparency, improved interoperability enabled the team to identify, discuss, and improve critical situations with a unified digital twin connected via USD. Additionally, there's work in progress to improve the usability and feature scope of tools.

Impact summary

The planning process for manufacturing facilities involves intricate coordination across various tools, datasets, and specialists globally. The integration of digital twins and virtual reality facilitated by Omniverse simplifies collaboration across locations and time zones and enables teams to collaborate seamlessly across virtual factories and achieve a unified perspective. This collaborative approach leads to fast and joint decision processes and increased efficiency, time and cost-wise, as it eliminates costly reorganisation after a production system has been built in real for BMW Group.

Future prospects

BMW Group aims to gradually integrate all pertinent product, process, quality, and cost data into Omniverse, alongside ongoing development, planning, and production processes and a transition of the infrastructure to cloud to scale for productive use. Additionally, future enhancements to the platform are anticipated to encompass "invisible" processes like energy and resource consumption tracking. Furthermore, BMW Group expects to leverage Omniverse to swiftly identify operational issues, minimising production downtimes. Including the 3D scan of all production sites, it's part of a global strategy to move from virtual images to vivid digital twins.

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[14] BMW Group (2023). Press Information. Subject BMW Group at NVIDIA GTC: Virtual Production Under way in Future Plant Debrecen. Date 21 March 2023. https://www.press.bmwgroup.com/global/article/detail/T0411467EN/bmw-group-at-nvidia-gtc:-virtual-production-under-way-in-future-plant-debrecen

CASE STUDY

IKEA – Use of AI and computer vision technologies to make sense of customers' home spaces[15]

Case overview

Ingka Group, the largest IKEA retailer, introduced IKEA Kreativ in 2022, a digital design experience powered by artificial intelligence. This platform enables customers to design and visualise their living spaces using computers and smartphones, integrating spatial computing, machine learning, and 3D mixed reality technologies. The technology utilises AI neural networks to recognise indoor objects and geometry, stereo vision algorithms for 3D visualisation, computational photography algorithms for detailed imagery, and mixed reality 3D graphics for realism.

Impact summary

IKEA Kreativ allows customers to explore IKEA products in 3D showrooms and envision their ideal living spaces from any location. The app has significantly improved customer engagement, with users spending an average of 3 minutes per session exploring and visualising IKEA products in AR. IKEA has reported a 98% increase in the likelihood of customers purchasing furniture after using the app.

Future prospects

Ingka aims to broaden IKEA Kreativ's customer base by offering features such as exploring virtual products and creating lifelike 3D replicas of personal spaces through the IKEA Kreativ Scene Scanner™ integrated into the IKEA App. This initiative seeks to enhance accessibility and empower individuals to seamlessly transition from inspiration to personalised home design.

[15] Ingka Group (2022). Corporate News: IKEA launches new AI-powered, digital experience empowering customers to create lifelike room designs. July 5, 2022.

Developing a European industrial cluster

From foundation technologies to commercialisation

Much of the foundational technology for the metaverse has already been invented and is now mature enough to facilitate limited participation. For instance, manufacturers have made significant progress in improving the design, comfort, performance and affordability of headsets and other multi-sensory peripherals.[16] However, further advances are necessary before the technology can foster large-scale commercialisation and deployment among consumers. An all-day wearable immersive headset may be the next platform for computing, but it remains elusive at this stage.

Although an authoritative and precise definition of the metaverse may help to foresee its technical requirements, the precise form of its nascent ecosystem will inevitably become clearer with the maturity of underlying components and governance protocols. Nonetheless, **the ecosystem is broadly composed of three distinct layers** discussed below:

- **Hardware, protocols, and standards –** including network infrastructure to enable connectivity, data hosting and transfer, and multi-sensory peripherals like headsets, glasses, and gloves.
- **Platforms –** where products, such as AI assistants, avatar accessories, virtual history lessons and digital twin factories, will be created and marketed. The layer also protects assets, security and privacy.
- **Experiences –** allowing end-users to immerse themselves in, e.g., architectural visualisations, retail experiences, games, real-time supply chain simulations or 3D imaging-guided medical diagnosis.

[16] Dwivedi et al., 2022

CASE STUDY

Bosch Sensortec – MEMS and displays

Company Overview

Bosch Sensortec GmbH, a fully owned subsidiary of Robert Bosch GmbH, develops and markets a wide portfolio of microelectromechanical systems (MEMS) sensors and solutions tailored for smartphones, tablets, wearables and hearables, AR and VR devices, drones, robots, smart home and IoT (Internet of Things) applications.

Role in the Ecosystem

Bosch Sensortec developed the world's smallest MEMS accelerometers (used to measure movement without a fixed reference) and has several inertial sensors for wearables and hearables, illustrating a notable advancement in sensor technology. These ultra-compact accelerometers and inertial sensors offer precise motion detection capabilities, enabling tracking movements in virtual environments within the metaverse. Additionally, Bosch Sensortec developed a smart connected sensors platform for full-body motion tracking, enhancing immersive experiences by accurately capturing and translating users' movements into virtual environments. Bosch Sensortec is also developing the world's first solution for a display perfectly integrated with a conventional pair of glasses with prescription lenses enabling all-day usage. The technology allows consumers to receive and view notifications, get navigation indications, access services, and learn "on the go" or "on the job".

Hurdles and incentives

The product portfolio also includes 3-axis accelerometers, inertial sensors and magnetometers, integrated 6 and 9-axis sensors, smart sensors, barometric pressure sensors, humidity sensors, gas sensors, optical microsystems and comprehensive software. Since its foundation in 2005, Bosch Sensortec has emerged as the MEMS technology leader in the markets it addresses and has, to date, sold more than 18 billion MEMS sensors.

"The metaverse will merge virtual and real worlds. However, essential technological building blocks are still missing for it – like the devices. It is now on Europe to act and push developments of key technologies – like the HMI (display) for Metaverse devices."

CASE STUDY

Ericsson – spearheading a mobile metaverse[17]

Company Overview

Ericsson, established in 1876 by Lars Magnus Ericsson, has transitioned from a telegraph repair workshop in Stockholm to a global leader in the telecommunications and technology sectors. Ericsson at a glance:

- Global market leader with $26 billion annual revenues in hardware, software & services
- More than 105,000 colleagues serving customers in 180 countries
- One of Europe's five largest technology companies by revenue (Fortune 500 Europe)
- 50% of the world´s 5G traffic outside mainland China carried over Ericsson's technology
- Number one telecom vendor in Europe with a market share of around 40%
- €4.1 billion annual R&D investments (17% of revenues)
- 21 European Research & Development centres in Europe
- 30,000 engineers and inventors, of whom more than 60% located in Europe
- 60,000 granted patents and more than 100 + signed license agreements

"Edge computing, also referred to as Mobile Edge Computing (MEC) or Multi-Access Edge Computing, is a distributed framework which brings processing and storage resources for applications closer to where data is generated or consumed. By keeping the compute capacity close to the users, devices or data sources, edge solutions deliver benefits such as low latency, high bandwidth, device processing and data offload, improving the performance, security, operating cost and reliability of applications and services."[18]

Role in the Ecosystem

Ericsson spearheaded a collaborative endeavour to enhance immersive VR experiences by leveraging 5G and edge technology, bringing together key players from the realms of technology and entertainment. The project united two ecosystems: one comprising technological giants including AT&T, NVIDIA, Qualcomm, and Ericsson, and the other hailing from the entertainment industry, represented by Wevr and Dreamscape Immersive.

Hurdles and incentives

One of the hurdles toward fully immersive VR experiences, according to Ericsson, is the lack of mobility. In collaboration with these five companies, the Ericsson private 5G network – optimised to support VR by the Ericsson D15 team – helped validate three important building blocks for future applications:

- Increased computing power: by moving computing power from a backpack laptop to a 5G network edge;
- Unrestricted movement: eliminating the wires between the headset and a computing source; and
- Multi-user capability: the enablement of a multi-useimmersive experience.

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[17] Ericsson, Case study Building the future of entertainment with 5G A collaborative approach to immersive VR experiences using 5G and edge technology. https://www.ericsson.com/49f0d2/assets/local/cases/building-the-future-of-entertainment-with-5g.pdf.

[18] See ericsson.com/en/edge-computing

CASE STUDY

STMicroelectronics – Sensing, Computing and Connecting; Enablers of the Metaverse

Case Overview

STMicroelectronics ("ST") develops semiconductor technologies with over 50,000 employees mastering the semiconductor supply chain with advanced state-of-the-art manufacturing facilities. ST is an integrated device manufacturer (IDM) with more than 200,000 customers and thousands of partners to design and build products, solutions, and ecosystems that address their challenges and opportunities, and is committed to support a more sustainable world.

Role in the Ecosystem

ST's broad technology and product portfolio, including microcontrollers and microprocessors, MEMS sensors and actuators, digital, analog and RF CMOS, silicon carbide, gallium nitride, image sensors, optics and photonics, will be critical to enable the immersive technologies that will power the metaverse. Through sensing, computing and connecting, ST supports the necessary components, devices, tools and solutions enabling gateways into the metaverse through a multitude of input devices, such as AR/VR devices, wearables, hearables and emerging product categories including smart clothing and biosensing.

Immersive eXtended Reality (XR) devices and applications have a fundamental requirement for highly efficient sensors. As an example, for head and hand tracking and movement in an immersive environment, the accuracy and speed of sensors is critical to ensure realistic user interfaces and to mitigate cybersickness. Enabling this level of performance requires a low signal-to-noise ratio (SNR) which also has the effect of increasing the power consumption, and a larger device size, which are both undesirable. ST develops sensors that can not only achieve the desired performance but do it while achieving low SNR and small form factors. In addition, ST adds "intelligence" to the sensors. ST sensors have built in AI capabilities on-board to provide contextual awareness and processing at the edge to enable advanced user interface controls.

As another example, ST's image sensors enable gaze tracking and eye tracking functions, as well as scene understanding and mapping, which when combined with ST's time-of-flight (ToF) sensors provides a robust platform for users to interact with the virtual content and enable spatial computing by supporting simultaneous localization and mapping (SLAM) algorithms. With ST's MEMS and image sensors, compelling user experiences can be realised. As the digital and physical worlds merge in the metaverse, security becomes even more important. ST offers a range of solutions under the ST Secure portfolio including mobile security, user authentication and secure connectivity, to ensure that users are protected as they transact in the metaverse.

Hurdles and Incentives

In summary, ST technologies facilitate interactions with and within the metaverse to deliver the ideal user experiences through multiple modalities of intelligent sensing (MEMS and optical), actuating, robust computation with machine learning & edge AI, and secure connectivity with the goal to enable platforms with ultra-low latency, ultra-low power, high performance with security and privacy. In addition, ST's technologies, devices and tools provide our customers and partners the ability to create innovative metaverse solutions for a multitude of applications relying on digital twins such as smart mobility, power & energy, cloud-connected autonomous things, smart homes, smart industries and smart cities of the future.


Turn Right
Then
15 min
1.5 kg

CASE STUDY

MICLEDI Microdisplays – pathway to future AR glasses

Company overview

MICLEDI Microdisplays, formed in 2019, is a spin-out from the Belgian R&D company IMEC. The company is privately held by European venture investors and institutions, including the investment arm of IMEC.

MICLEDI Microdisplays specialises in developing micro-LED display modules tailored for augmented reality (AR) glasses, positioning itself as a significant contributor within the metaverse ecosystem. Leveraging a fabless manufacturing model, the company focuses on integrating micro-LED technology into AR glasses, with a particular emphasis on addressing critical challenges such as brightness, power efficiency, and image quality.

The core technology employed by MICLEDI is engineered to be compatible with a high-volume foundry (300mm Si-CMOS) that facilitates cost-effective manufacturing—a crucial factor for the widespread adoption of AR glasses within the metaverse. MICLEDI is building a European fabless manufacturing supply chain by teaming up with commercial epi-supplier IQE (UK) and announced a collaboration with GlobalFoundries (GF Dresden) for the high-volume production of the microLED display wafer. First small-volume production will be available in 2026, with high-volume manufacturing available in 2027.

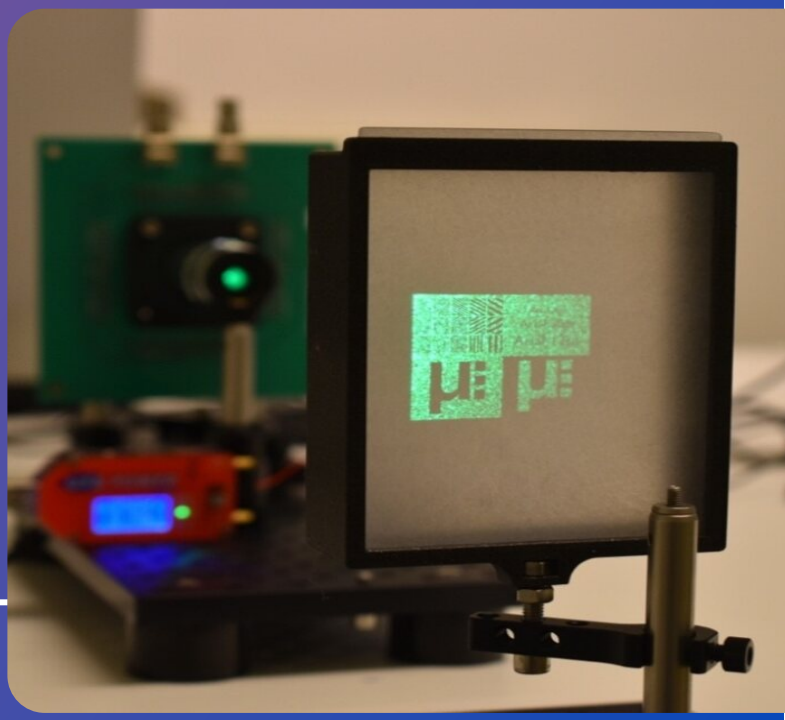
Role in the Ecosystem

Adapting AR glasses for outdoor daylight usage demands exceptionally bright and low-power display engines; existing micro-displays often fall short, either lacking sufficient brightness or exhibiting visual artefacts. This underscores the importance of delivering a seamless and high-quality visual experience to users, similar to the standards set by 2D mobile devices.

Micro-LED technologies offer a promising solution to these challenges, presenting a pathway to future AR glasses equipped with micro displays boasting low power consumption, high brightness levels, and superior image resolution packaged within a compact and lightweight form factor.

Hurdles and incentives

Addressing this challenge requires a concerted effort towards supporting deep tech start-ups, especially in domains such as optics, actuators, sensors, and communication. While Europe boasts a wealth of innovative ideas, scaling these ventures demands resources unavailable to most private investors. Consistent and risk-tolerant government investment is essential to nurture the development of new hardware components critical for driving the widespread adoption of the metaverse.



Hardware, protocols and standards

High-speed networks are essential to support real-time communication, data streaming, and seamless interactions across virtual spaces. The majority of XR content is consumed over fixed networks. As a 'once in a generation' investment, existing fibre deployments already support speeds of 2.4 gigabits-per-second, latency lower than 20 ms, with prospective upgrades yielding speeds of up to 50 gigabits per second on the same underlying fibre.[19] For use cases in the field or in public spaces, 5G can support speeds of up to 1 gigabit per second. Current and future generations of networks have ample potential to address demand for the metaverse – and Europe is the home to the two leading companies at the centre of global supply.

Building on high-quality network infrastructure, the metaverse will require additional computational power.[20] **Advances in cloud computing** are necessary for processing capacity and storage, while EDGE computing will relocate applications and data closer to the end-user to facilitate a more seamless experience. Looking further ahead, high-performance computing (HPC) and quantum computing may be needed to support ever-more-real interactions, simulations, and renderings.[21]

Here, Europe has much experience in designing power-efficient application-specific integrated circuits **(ASICs)**.[22] It also commands key manufacturing technologies, including extreme-UV (EUV) lithography and other wafer-fabrication equipment that are central for the most advanced chips.[23] Europe is also well-advanced in the coming generation of compound semiconductors (based on gallium-arsenide or gallium-nitride) that outperform silicon;[24] and, similarly, European actors are leading the pilots on Fully Depleted Silicon on Insulator (FD-SOI) – a planar process that provides an alternative solution to overcome the limitations of today's mass IC technology at nodes below 12 nm.

Connected devices have enjoyed spectacular advances in recent years. In particular, headsets and smart glasses have exhibited impressive improvements in processing and sensory technology. Issues still persist, but these devices are already facilitating immersive 3D experiences. **Haptic technologies** have also made strides from alerts and vibrations to mimicking the feel of natural materials and interactions.[25] With that said, gloves and other wearables remain confined to experimental use cases, with technical limitations and cost levels that inhibit mass adoption.

Aside from personal devices, the **Internet of Things (IoT)** is proving central to the metaverse as a means of real-time mapping and control, particularly in terms of its industrial applications. Manufacturers are already leveraging IoT devices with immersive technologies for enhanced monitoring, diagnostics, and simulations. For example, combining metaverse with IoT allows maintenance teams to locate and solve anomalies virtually in a "digital twin" before dispatching a team in the physical world. Europe (and Germany in particular) have a very high uptake of IoT. [26] **Smart manufacturing** is forecast to proliferate with access to advanced computing, data processing and analytics, including edge AI chips, which are relocating decision-making and other capabilities from the network core towards the device.[27]

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[19] Salvadori & Martin, 2023
[20] Carlini, 2022
[21] supra note 3
[22] Financial Times, 2022. Accessed at: https://www.ft.com/content/b31e27fd-0781-4ffd-bb69-9af985abff41
[23] Ibid.
[24] European Council, 2022. Accessed at: https://data.consilium.europa.eu/doc/document/ST-8799-2022-ADD-1/en/pdf
[25] Haseltine, 2023
[26] supra note 12
[27] supra note 3

Indeed, electronics and photonics are integral to the progress of connective devices. **Next-generation chipsets** will further enhance processing power and reduce energy usage. Meanwhile, energy-harvesting and self-generated sensors and actuators are increasingly adopted as an alternative to battery power.[28] In **photonics** – an area where European R&D is particularly prominent,[29] developments like micro-LED displays, laser-beam scanners (LBS), waveguides, meta-surfaces and liquid lenses offer low-power means to improve user visualisation and immersion.

Protocols and standards can be overlooked as a foundation of the metaverse, but they are essential for industry interoperability. Standards on hardware, software, communication protocols, and security mechanisms will help to promote transparency and reduce development costs. Established standardisation development organisations (SDOs) like the ITU and IEEE are currently developing metaverse and digital twinning standards,[30] while new dedicated forums like the Metaverse Standards Forum are also emerging.[31] Within the EU, Horizon Europe has launched a project to develop EU standards for XR.

Platforms and experiences

The establishment and maturation of **platforms** will be fundamental to immersive synergies and the creation, delivery, and accessibility of high-quality content. Existing platforms allow stakeholders to build and share specific XR content and "assets", but a synchronous and ambient metaverse remains nascent. Its realisation is contingent on the continued development of scalable and modular solutions, ideally within the context of clear standards which can facilitate compatibility as hardware advances.[32]

Building on platforms and systems, **user-generated content and experiences** are a cornerstone of the metaverse. Creating XR content generally entails technical development and design, and businesses and consumers are already leveraging tools to produce and share their own XR content.

One European example of existing user-generated content has been the proliferation of **digital twins** for product design, supply chain management, quality assurance, and predictive maintenance. Notably, Germany has established an industrial association in digital twinning. The Industrial Digital Twin Association (IDTA) gathers the key players of the German industry and also develops an asset administration shell (AAS) with standardised digital representations of various assets and sub-models.[33]

Finally, 3D modelling has mandated specialist equipment and expertise in the past, but recent progress in **LiDAR** (light detection and ranging) and photogrammetry software have heightened accessibility,[34] and developments in spatial computing can enhance content creation and experiences. Meanwhile, generative AI will increasingly enable the creation of 3D content and experiences without needing specialised technical expertise or design skills as we work towards being able to build rich virtual environments created simply through human prompts.

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[28] Shi, 2020
[29] Picot-Clemente, J., presentation at AWE2023
[30] ITU, accessed at: https://www.itu.int/en/ITU-T/focusgroups/mv/Pages/default.aspx
[31] Metaverse Standards Forum, accessed at: https://metaverse-standards.org/
[32] Deloitte Insights, 2023
[33] IDTA, accessed at: https://industrialdigitaltwin.org/en/
[34] supra note 3

Strengths of the European innovation system

A strong EU-wide network of hardware, software and content is imperative for ecosystem expansion, especially in terms of the development of innovative, use-case-specific applications. European developers also enjoy unfettered **access to a technologically adept global market** that specialises in advanced manufacturing and is likely to stimulate high demand for professional metaverse applications.

The **European value chains** have many competitive strengths and advantages. Elsewhere, international cooperation will be necessary to maximise other technical elements. Here, EU and G7 policies typically balance regulatory priorities with open interoperability and a business environment that allows European innovation to acquire and integrate foreign technologies. In this regard, Europe's leadership in trade and commercial policy continues to play an important role in market access and open supply chains.

Europe's innovation ecosystem is also unique thanks to its **close cooperation between industry and RTOs**.[35] The industry typically guides the RTOs, who then mature the technology before transferring it back to industrial partners for commercialisation. Yet, Europe has not always successfully turned its R&D excellence into manufacturing opportunities. Since the 1970s, Europe and the US have retained capital-intensive market activities at home while transferring innovations to East Asia for more labour-intensive tasks. Western economies began outsourcing labour-intensive mass production to Japan in the 1970s and moved downstream to the "Asian tigers",[36] before finally outsourcing to China after its accession to the World Trade Organization.

It is not given that this global division of labour – where Europe innovates but does not produce – will pay sufficient dividends. The **Chinese government has also recognised the importance of the metaverse** in sustaining its global competitiveness and is scaling up its efforts to create an indigenous metaverse within three years.[37] Evidently, R&D in areas like semiconductors is becoming increasingly competitive through large-scale government interventions.

In response, the EU has enacted the **EU Chips Act**, which, through its Chips for Europe Initiative, is meant to reinforce technological leadership and facilitate the commercialisation of R&D.[38] This initiative is supported by €11.5 billion in public funds for R&D, including a repackaging of existing Horizon Europe funds into a Chips Joint Undertaking. Here, entities like Leti, IMEC and Fraunhofer are putting forward funding proposals that have significant implications for developing metaverse hardware in Europe. While the EU Chips Act signals an important and stable public commitment to European R&D, the funding must be compared to some competitor programs like the US CHIPS Act, which pledges $52 billion for R&D and manufacturing incentives.

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[35] Blau, J., 2009
[36] Hobday, M., 1995
[37] Ministry of Industry and Information Technology of PRC, accessed at: https://www.gov.cn/zhengce/zhengceku/202309/content_6903023.htm
[38] European Chips Act: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

Impediments on innovation

Improving commercial incentives

While much of the foundational technology behind the metaverse may have already been invented, only some aspects are optimised for a user experience that is ready for large-scale commercialisation. One industry representative sums up the challenge as "immersive wearable devices must be light-weight, fashionable, display high-resolution content, and high-performing while able to run the entire day on a single charge – yet available at an affordable price point – to have mass appeal".[39] Each of these criteria are individually difficult and jointly, they present an **extreme innovation challenge across multiple technology domains**.

In particular, European suppliers of key components stress the need for **better incentives** to prioritise metaverse development before other more short-term business priorities. The foundational technology behind components like displays, batteries or chipsets is often co-funded by EU public funding already. However, these technologies must support many other commercial applications besides the metaverse with more immediate returns. Many commercial organisations describe a dilemma: There is a mismatch between investments into metaverse R&D that are immediately needed, whereas its returns are on a ten-year horizon.[40]

There is other evidence which suggests that research continues to be inhibited by limited funding. AR and VR companies have reported a **shortage of available venture capital**, a lack of industry awareness and supporting market data, or misconceptions about the scope and growth potential of metaverse technologies.[41] Firms allude to the absence of an entrepreneurial mentality in Europe, relative to other markets like the US. These sentiments are far from exclusive to AR and VR, and the European Investment Bank suggests that the VC ecosystem has underperformed on the metaverse and other complementary technologies like AI as well.[42]

Conversely, stakeholders have also cited the **accessibility of public funding** as problematic to research on metaverse technologies. While initiatives like Horizon 2020 and Creative Europe have helped to finance related projects, the application process is reported as burdensome, and even perceived to favour bigger companies as a result of the time and expertise required.[43] More broadly, the current EU framework for public support has been described as ill-suited to the synergies typically required for metaverse research. For example, the majority of existing instruments address either R&D funding for technological development or cultural content support rather than a combination of the two.[44]

In addition to the funding gap, the EU industry also points to how the metaverse is also an unprecedented innovation challenge.[45] Metaverse R&D is more than just assembling its functional parts and presents a major integration and optimisation challenge for new hardware, software and design tools. It presents an innovation challenge that is not just "super-heterogenous" but even "**hyper-heterogenous**" – that radically changes how we design and build. In addition, the need for new software and design tools adds another layer of complexity.

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[39] Interviews and consultations at the LSE-Meta workshop on October 24, 2023
[40] Ibid.
[41] VR/AR Industrial Coalition, 2022
[42] EIB, 2021, 2023
[43] Kelly, 2017
[44] supra note 36
[45] supra note 34

These industry opinions align with written industry testimonies: The **fragmentation of EU networks** is frequently cited as a major challenge for R&D in immersive technologies.[46] Certain pan-European initiatives, such as XR4Europe – a non-profit resulting from the EU Horizon 2020-funded project – have attempted to promote synergies between AR and VR stakeholders.[47] But rapid business developments typically require more intense forms of collaboration that also extend to hardware in addition to platforms and content.[48] Researchers and other stakeholders have reiterated the need for tools, such as a networking framework and the establishment of common standards, to reduce ecosystem fragmentation.[49]

While the EU and the Member States excel in funding individual foundational technologies, they often fall short of executing **a coherent and long-term vision**. The EU is typically not well-equipped to handle the integration of dense applications of multiple technologies like the metaverse. Yet, the EU has successfully tackled similar heterogeneous R&D and design challenges by establishing a network of modular clusters across multiple regions and technologies for a major industrial undertaking, such as creating the European mobile network industry around GSM, restructuring the auto industry, or launching the Airbus project.[50] Becoming an innovation leader for the internet will require a similar, long-term commitment. Airbus created a competitive European cluster by consolidating existing champions into a more viable network that achieved greater leverage by combining resources and expertise from multiple countries and segments. Similarly, the European metaverse suppliers could hold greater clout against more short-term competing interests.

Promoting adoption and trust

Despite the many industrial applications, the metaverse ecosystem is a mass market technology, like the web and other common internet applications. But before there is sizeable demand, the European industry must take a leap of faith to develop technologies that will make the metaverse a reality. Moving on from the supply-side discussions onto the demand-side, European governments can do more to **scale the market and demand**, making the metaverse pervasive.

Industry representatives interviewed for the project stress how the maturation of content, apps, platforms and assets is fundamental for adoption. And given Europe's linguistic and cultural diversity, much of the task of promoting the adoption and development of content or applications with broad consumer appeal falls on **national and regional governments**. Building a sustainable business in arts and entertainment in local languages is increasingly difficult – why public funding is a major differentiator that also attracts international productions to Europe. In 2023, the prestigious Venice International Film Festival announced its official immersive selection for Biennale Cinema 2023 with 43 projects from 25 countries.[51]

National and regional governments are also often responsible for **public education**, where the pandemic revealed both the potential and limitations of two-dimensional online learning. While Horizon Europe projects like XR2Learn and XR4ED have also been set up to promote XR for learning and education specifically at an EU level, deployment depends on the execution at national and regional levels. With immersive technology, schools can offer the same accessibility as current web-based learning without sacrificing social interaction. In addition, students of all backgrounds may experience distant environments, increasing equity and cost-efficiency and

[46] VR/AR Industrial Coalition, 2021
[47] XR4europe, 2023
[48] supra note 34
[49] Ibid.
[50] Monnoyer, Zuiliani, 2007; Pachura, P., 2010.
[51] Vienna International Film Festival, 2023

improving learning outcomes. Surveys suggest that 40% of VR learners are more confident in applying what they've been taught and 150% more engaged during classes.[52] 77% of educators also believe these technologies ignite curiosity and improve engagement in classes.[53] As for training purposes, a study on emergency response showed that 70% of those trained in VR performed 50% higher than a control group who were instructed via presentations and reading materials.[54]

Besides the availability of persuasive content, market scale is also a function of **user trust** and acceptance. Bringing in augmented, richer and more social experiences, the metaverse will change how we interact with the Internet. It must be grounded in human-centric dimensions of safety, sustainability, inclusion, diversity, and well-being. Pursuing the development of innovation and the protection of fundamental rights and human values will therefore be critical for this technology to take off.

Europe has been at the forefront of global thinking on this matter. Indeed, the European Commission (2023) has already delivered an ambitious strategy for Web 4.0 and all immersive technologies, accompanied by a concrete action plan advocating for a human-centric development of the technology. The strategy underlines that Europe's robust, future-oriented legislative framework already applies to several aspects of the development of virtual worlds and does not foresee any product-specific legal framework for the metaverse. While there might be market challenges that cannot be predicted today, European businesses can benefit from this **legal predictability and stability** for the foreseeable future.

This paper precisely aspires to discuss the development of metaverse and immersive technologies in Europe and proposes concrete recommendations aiming to add up to the unique advantages of European companies to seize the opportunities they will open.

Among businesses and industries, a heightened awareness of existing and prospective use cases is vital to technological dissemination. According to the literature,[55] management interest and willingness to promote AR and VR within a company are still key barriers to adoption amongst many EU firms. In this sense, practical experience and testing of devices and software by management is crucial in providing a better understanding of technological applicability and limitations and in securing the necessary resources for successful adoption. As a means to furthering the industry's understanding of the metaverse, stakeholders have underscored the importance of **awareness-raising initiatives**, including demonstrations, exhibitions, and roadshows.[56]

The **compatibility** of metaverse technologies with existing digital infrastructure is another important determinant of adoption.[57] For European businesses, compatibility with firm-level architecture is also salient. Even where AR and VR applications are recognised as useful, their interoperability with established information systems can be fundamental to organisational implementation.[58] Similarly, firms have reported difficulties in integrating legacy assets (like 2D design drawings) into metaverse processes. Here, path dependence from earlier business choices represents another barrier to adoption.[59]

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[52] PwC, 2022
[53] XRA, 2023
[54] supra 48
[55] Jalo et al., 2022
[56] Ecorys, 2021
[57] WIK Consult, 2018
[58] Dwivedi et al., 2022
[59] supra note 46

Looking further ahead, the development of nascent complementarities will prove increasingly integral to industry uptake. **AI** can be used in tandem with the metaverse for object recognition, natural language processing and predictive analytics.[60] Concurrent adoption of technologies is therefore necessary to fully embrace many use-case-specific applications. However, evidence suggests that the EU lags behind its peers in the uptake of AI, blockchain and related products and services.[61]

Securing competences

As a cornerstone of cutting-edge research and widespread adoption across industries, developing world-class talent is essential to unleash the potential of the Metaverse in Europe. The VR/AR Industrial Coalition estimated in 2021 that the sector already accounts for around 400,000 European jobs, while more employment opportunities are expected.

To begin, **competition for engineers and researchers** is already fierce, with many firms unable to attract the requisite expertise, and there is increasing concern of a "brain drain", with some of the continent's best talent lured to the US and Asia by more attractive salaries and working opportunities.[62] Training and retaining first-class researchers and engineers in computer science, physics, electrical engineering and other fields are prerequisites for building an R&D cluster for immersive technologies. Semiconductor Industry representatives recount how it takes up to a year or longer to fill a research vacancy, and the skills gap severely limits EU innovation on immersive technologies.

The shortage of skilled metaverse professionals extends beyond R&D. Interviewed companies across a range of industries reported difficulties in finding **metaverse-literate employees** as a major barrier to both research and adoption.[63] Businesses report employee resistance towards adopting AR and VR solutions as a significant impediment to successful implementation initiatives.[64] Currently, companies with more traditional engineering disciplines, like automotive manufacturing, are also losing out to gaming and other creative industries, which are generally considered more attractive for professionals with technical skills in immersive technologies.[65]

So far, most public programmes have primarily focused on content production. In Germany for instance, the Federal Ministry for the Economy and Climate (BMWK) has announced an "immersive media design programme" as one of the first publicly supported efforts for Web 4.0.[66] While these metaverse-specific content-creator programmes are ground-breaking and show great promise, but AR and VR must be integrated into the curriculum of **existing engineering and technical degrees**.

In view of existing talent shortages and future requirements for metaverse-literate staff, a range of stakeholders have reiterated the need for **accessible education and training programmes**.[67] Meta has also launched a Metaverse Academy in France, to train immersive technology developers and support technicians.[68] More broadly, there have been calls to incorporate AR and VR elements in university courses and vocational training, as well as increasing AR and VR applications in schools to utilise knowledge transfers and heighten awareness.[69]

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[60] Intellect Data, 2023
[61] EIB, 2021
[62] Bozorgzadeh, 2018
[63] Jalo et al., 2022
[64] Cottereau, 2021
[65] supra note 36
[66] BMWK, 2023
[67] Ibid.
[68] See: https://about.fb.com/fr/news/2022/06/meta-et-simplon-co-lancent-lacademie-du-metavers-pour-former-les-talents-aux-metiers-de-demain/
[69] Ecorys, 2021

Concluding recommendations

Commissioner for the Internal Market, Thierry Breton, envisions the metaverse as a place "to work together, develop artistic creativity, do real-life simulations aimed at medical interventions, cultural preservation, environmental protection or disaster prevention and a lot more".[70] Indeed, this note has highlighted several examples of innovative solutions by European companies where the metaverse boosts productivity and competitiveness.

Europe commands an emerging ecosystem with firms present across the entire value chain – from hardware and infrastructure to standards setting, platforms and applications. However, the full potential of the metaverse cannot be realised without further innovation and adoption. This leads to the following policy recommendations:

Recommendation 1: An EU industrial policy supporting a European innovation and industrial network for the metaverse.

Thanks to its R&D leadership and existing clusters in many related areas – including photonics, micro-LEDs, materials, semiconductors (including sensors and ASICs) and mobile infrastructure – Europe is on the verge of becoming the global industrial hub to build the next iteration of the web. Such an immersive tech cluster in Europe – an Airbus for the metaverse – can be developed by:

- Integrating existing clusters into a network of facilities, suppliers, RTOs and universities for the great engineering challenge of building an immersive internet. At its core, this proposition requires a long-term political commitment to pan-European industrial policy.

- A European immersive industrial cluster needs to be underwritten by a dedicated financial instrument that can pool EU, national and industry resources. A dedicated instrument for the metaverse could be modelled on many different strategic instruments that support the development of critical technologies in Europe, e.g. Joint Undertakings, such as the one on chips (Chips JU), high-performance computing (HPC JU) or Smart Networks and Services (SNS JU). The cluster could also be suited for a designation as an Important Project of Common European Interest (IPCEI) or an EU Alliance.

- While a successful European VR/AR alliance already exists, the industry should explore a manufacturing alliance for developing common specifications. Similar to how the US and China support open and collaborative industry alliances to catch up with Europe in areas like radio access networks, Europe could build its metaverse leadership by championing an open industrial alliance, but with interoperability and genuine openness towards global collaboration.

Recommendation 2: Secure access to researchers and skilled workforce in Europe.

An immersive industrial cluster will contribute to specialised internet engineering expertise in Europe. While national and regional governments must support engineering and research education programmes more broadly, immersive technologies can also make these programmes more attractive. Access to talents and a skilled workforce can be developed by:

[70] Breton, 2022

- National skills supply planning should prioritise training and retaining first-class researchers and engineers. Foundational research and commercialisation of immersive technologies are critical for metaverse development.

- Besides creating separate silos with "metaverse degrees", immersive technologies and their applications (like digital prototyping and twinning) should become integral parts of the curriculum for civil engineers, architects, and other technical degrees.

- Competitive industrial and services regions should aim to establish vocational, SME and on-the-job training for Web 4.0 and immersive tools.

Recommendation 3: Help to foster demand, scale and promote a genuinely open environment.

Scale is necessary for EU innovations to be competitive and commercially viable. While the metaverse and Web 4.0 have many industrial applications, the internet will remain a mass-market application. To promote an inclusive environment capable of competitive innovation and widespread technological adoption:

- The EU is already equipped with a future-oriented legislative framework, and the protection of consumers and vulnerable groups should apply equally to the current iteration of the internet and the metaverse. Metaverse could also bridge the gap between the Single Market and the Digital Single Market as the consumer experiences online and offline will converge.

- National and regional governments should extend their promotion of audiovisuals in their local languages to the metaverse. Such support will also foster a metaverse that also reflects the diversity of Europe. Opportunities include the European Media and Audiovisual Action Plan and support for alliances like the VR/AR Industrial Coalition. These types of programs are fundamental to scaling demand for the metaverse.

- Public bodies, including the EU institutions, to utilise immersive technologies and incorporate them as part of forthcoming public procurements in information technology. EU and national grants can also be set up in areas like public education at various levels. Learnings from the pandemic suggest immersive technologies can improve the learning experience and enhance social interaction.

- Continue to support trusted networks (such as 5G/6G and WiFi), as trusted connectivity is critical to the metaverse, where in particular 5G/6G, will be used for mobility use cases, and WiFi for personal area use cases.

- Prioritise EU industry participation in international standard-development organisations and developer forums like web3D and Metaverse Standards Forum to extend influence. Policy support for standardisation is also needed to promote standardised assets and sub-models that will also facilitate SME up-take and user-generated content.

- Mobilise EU trade policy for the reciprocal removal of duties and technical barriers to trade that affect market access for European immersive technologies and components.

Bibliography

Adidas. (2023). Into the metaverse. https://www.adidas.co.uk/metaverse

Agarwal, A. (2022, June 20). Europe on track to become global VR leader. XR Association. https://xra.org/europe-on-track-to-become-global-vr-leader/

Analysis Group. (2022). The Potential Global Economic Impact of the Metaverse. https://www.analysisgroup.com/globalassets/insights/publishing/2022-the-potential-global-economic-impact-of-the-metaverse.pdf

Ark, B., Inklaar, R., & Mcguckin, R., 2003. The Contribution of ICT-Producing and ICT-Using Industries to Productivity Growth: A Comparison of Canada, Europe and the United States. *International Productivity*

BMW. (2022). This is how digital the BMW iFactory is. BMW Group. https://www.bmwgroup.com/en/news/general/2022/bmw-ifactory-digital.html

BMWK. (2023, April 20). In virtuelle Welten eintauchen – BMWK schafft neuen Ausbildungsberuf „Gestalterinnen und Gestalter fur immersive Medien". Bundesministerium für Wirtschaft und Klimaschutz. https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2023/04/20230413-in-virtuelle-welten-eintauchen.html#:~:text=Gestalter%2F%2Dinnen%20f%C3%BCr%20immersive,f%C3%BCr%20die%20Auszubildende%20qualifiziert%20werden

Bozorgzadeh, A. (2018, March 17). Europe needs to halt its startup brain drain to the U.S. VentureBeat. https://venturebeat.com/entrepreneur/europe-needs-to-halt-its-startup-brain-drain-to-the-u-s/

Breton, T. (2022, September). People, technologies & infrastructure – Europe's plan to thrive in the metaverse I Blog of Commissioner Thierry Breton. European Commission. https://ec.europa.eu/commission/presscorner/detail/de/STATEMENT_22_5525

CGarchitect. (2016). Survey results: VR usage in arch viz. https://www.cgarchitect.com/features/articles/919b2174-survey-results-vr-usage-in-arch-viz

Cottereau, T. (2021). Reducing resistance to AR adoption: Four ideas for change management. Field Technologies Online. https://www.fieldtechnologiesonline.com/doc/reducing-resistance-to-ar-adoption-four-ideas-for-change-management-0001

Damar, M. (2021). Metaverse Shape of Your Life for Future: A bibliometric snapshot. Journal of Metaverse. https://dergipark.org.tr/en/pub/jmv/issue/67581/1051371

DHL. (2019). DHL Trend Report: Implementation of digital twins to significantly improve logistics operations. https://www.dpdhl.com/en/media-relations/press-releases/2019/dhl-trend-report-implementation-digital-twins-significantly-improve-logistics-operations.html

Dwivedi, Y., Hughes, L., Baabdullah, A., Ribeiro-Navaratte, S., & Giannakis, M. (2022). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. International Journal of Information Management, 66. https://www.sciencedirect.com/science/article/pii/S0268401222000767

Ecorys. (2021). XR and its potential for Europe. https://xreuropepotential.com/assets/pdf/ecorys-xr-2021-report.pdf

EIB. (2021). Artificial intelligence, blockchain and the future of Europe: How disruptive technologies create opportunities for a green and digital economy. Startseite | Europäische Investitionsbank. https://www.eib.org/attachments/thematic/artificial_intelligence_blockchain_and_the_future_of_europe_report_en.pdf

EIB. (2022). Digitalisation in Europe 2021-2022: Evidence from the EIB Investment Survey. European Investment Bank. https://www.eib.org/attachments/publications/digitalisation_in_europe_2021_2022_en.pdf

EIB. (2023). EIB Investment Survey 2023: European Union overview. https://www.eib.org/en/publications/online/all/eib-investment-survey-2023

EPRS. (2022, 6). Metaverse: Opportunities, risks and policy implications | Think tank | European Parliament. https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)733557

European Commission. (2023). Virtual worlds fit for people. https://digital-strategy.ec.europa.eu/en/policies/virtual-worlds

Green, N., & Works, K., 2022. Defining the Metaverse through the lens of academic scholarship, news articles, and social media. *Proceedings of the 27th International Conference on 3D Web Technology*. https://doi.org/10.1145/3564533.3564571.

Intellect Data. (2023). The Role of AI in Augmented and Virtual Reality. https://intellectdata.com/the-role-of-ai-in-augmented-and-virtual-reality/

Jalo, H., Pirkkalainen, H., Torro, O., Pessot, E., & Zangiacomi, A. (2022, June). Extended reality technologies in small and medium-sized European industrial companies: level of awareness, diffusion and enablers of adoption. Virtual Reality. https://link.springer.com/article/10.1007/s10055-022-00662-2

Kelly, E. (2017). Horizon 2020's continued funding of big companies should be questioned. Science|Business. https://sciencebusiness.net/news/80199/Horizon-2020%E2%80%99s-continued-funding-of-big-companies-should-be-questioned

Labster. (2023, May 16). Labster secures $47M in new funding. Labster | Virtual Labs for Universities and High Schools. https://www.labster.com/news/new-funding-april-2022

Lee-Makiyama, H., Baker, R. (2024, forthcoming). German industrial competitiveness and the metaverse. ECIPE.

Market Research Future (2021), ARVR Market research report – Global forecast till 2027

Meta. (2022, December 6). Supporting independent Metaverse research across Europe. https://about.fb.com/news/2022/12/supporting-independent-metaverse-research-across-europe

Meta. (2023). The metaverse and the opportunity for the European Union.

Osterrieder, P., Budde, L., & Friedli, T., 2020. The smart factory as a key construct of industry 4.0: A systematic literature review. *International Journal of Production Economics*, 221, pp. 107476. https://doi.org/10.1016/j.ijpe.2019.08.011.

PwC (2019), Seeing is believing

PwC. (2022, September). How virtual reality is redefining soft skills training. https://www.pwc.com/us/en/tech-effect/emerging-tech/virtual-reality-study.html

Ritterbusch, G., & Teichmann, M., 2023. Defining the Metaverse: A Systematic Literature Review. IEEE Access, 11, pp. 12368-12377. https://doi.org/10.1109/ACCESS.2023.3241809.

Schickler, J. (2023). France Publishes Metaverse Consultation, Seeking Alternative to Dominance by Web Giants. Yahoo. https://uk.sports.yahoo.com/news/france-publishes-metaverse-consultation-seeking

Statista. (2023, April). AR & VR - Europe. https://www.statista.com/outlook/amo/ar-vr/europe?currency=USD#revenue

Tampere University. (2019). Tampere University is revolutionising medical imaging with the help of virtual reality and AI. https://www.tuni.fi/en/news/tampere-university-revolutionising-medical-imaging-help-virtual-reality-and-ai

VR/AR Industrial Coalition. (2021). VR/AR industrial coalition: Defining EU VR/AR optimal deployment by 2026. European Commission. https://digital-strategy.ec.europa.eu/en/library/vrar-industrial-coalition-defining-eu-vrar-optimal-deployment-2026

VR/AR Industrial Coalition. (2022). VR/AR industrial coalition: Strategic paper. Publications Office of the EU. https://op.europa.eu/en/publication-detail/-/publication/9aaef6fd-28db-11ed-8fa0-01aa75ed71a1

Wang, G., Badal, A., Jia, X., Maltz, J., & Mueller, K. (2022). Development of metaverse for intelligent healthcare. Nature machine intelligence, 4, 922-929. https://www.nature.com/articles/s42256-022-00549-6

WIK Consult. (2018). The Benefits of Ultrafast Broadband Deployment. Ofcom. https://www.ofcom.org.uk/__data/assets/pdf_file/0016/111481/WIK-Consult-report-The-Benefits-of-Ultrafast-Broadband-Deployment.pdf

XRA. (2023). Accessed at: https://xra.org/research/insights-from-teachers-on-future-of-xr-for-education/

XR4europe. (2023, April 4). About. XR4EUROPE. https://xr4europe.eu/about-us/