Chapter 5. Digital supply chains and the industrial metaverse

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5.1 Introduction

Digital supply chains are the expression of a far-reaching transformation of methods of production, distribution and consumption of goods and services, based on the intensive use of digital technologies such as artificial intelligence, the internet of things, cloud computing, blockchain, and augmented and virtual reality. Digital supply chains allow companies to create new business models, optimise processes, improve quality and security, reduce costs and environmental impacts, and increase competitiveness and resilience.

The metaverse is a vision of a shared and immersive virtual world in which people, things and information interact in real time through a range of platforms and devices. The metaverse is not only a place for entertainment or social contact, it is also a space for innovation and opportunity for businesses, particularly those operating in the manufacturing sector.

The industrial metaverse can be described as the convergence between the metaverse and digital supply chains; in other words a virtual environment in which companies can simulate, monitor, control and improve their activities throughout the value chain by integrating real-world data with the data and functionalities offered by the digital world. The industrial metaverse constitutes a new frontier for innovation and sustainability that can generate added value and competitive advantage.

However, the industrial metaverse also brings challenges and risks in terms of both technology and legislation. In order to build the industrial metaverse, companies need to address problems relating to connectivity, scalability, security, privacy, intellectual property, governance, standardisation, interoperability, data quality and skills development. In addition, companies must comply with the rules and obligations imposed by national and supranational authorities, the European Union in particular, in matters of social and environmental responsibility.

This article will analyse the concept and characteristics of the industrial metaverse, examine the opportunities and challenges it presents to companies, touch upon the EU's legislative framework, with particular reference to the

Supply Chain Due Diligence Directive, and illustrate some examples and case studies of the industrial metaverse's application in different sectors and fields.

5.2 The concept and characteristics of the industrial metaverse

The term metaverse is a blend of the words meta (beyond) and universe, and describes a parallel alternative universe in which people can interact with each other and with things through virtual characters known as avatars. The metaverse was originally conceived as a form of science-fiction narrative, but in recent years it has taken on a more technological and practical connotation, thanks to the development of platforms and tools that allow the creation of and access to increasingly realistic and immersive virtual worlds.

The industrial metaverse is a specific variant of the metaverse, which focuses on industry and its needs and peculiarities. The industrial metaverse is a virtual environment in which companies can duplicate and manage their activities throughout the value chain, combining real-world data with the data and functionalities offered by the digital world. The industrial metaverse is underpinned by a number of key technologies, including:

- Digital twins: virtual representations of real-world objects, processes, systems or services which reflect their status, behaviour or performance thanks to the collection and analysis of data from sensors, devices and various sources. Digital twins allow industrial activities to be simulated, monitored, controlled and improved, thus reducing risk, costs and times, while increasing efficiency, quality and security.
- Augmented and virtual reality: the methods used to access and interact with the virtual world, based on devices such as goggles, visors, helmets and gloves that overlay or replace perceived reality with digital elements like images, video, sound, text and graphics, and thus enrich or modify the user experience. Augmented and virtual reality allow the creation of and access to the industrial metaverse by offering greater immersion, engagement and collaboration among operators and between these and machines.
- Artificial intelligence: a discipline that designs and builds systems capable of carrying out tasks that would normally require human intelligence, such as learning, reasoning, decision-making, communication and creativity. AI allows real-world and virtual-world data to be elaborated and interpreted in order to provide information, suggestions and solutions, automate and optimise processes, and generate innovative and personalised content and features.

The industrial metaverse has several distinctive characteristics that differentiate it from the generic metaverse or other forms of virtual reality. One of these is the degree of realism and accuracy with which the industrial metaverse duplicates the real world, both visually and functionally. The industrial metaverse needs to be able to capture and transmit the details, properties, relationships, dynamics, variables and events that characterise industrial activity in order to provide a realistic and reliable representation that allows companies to operate effectively and efficiently.

A second important factor is scalability, in other words the ability to adapt to and manage a high and variable number of users, objects, data and operations interacting in the industrial metaverse. The industrial metaverse has to be able to support and coordinate enormous and growing complexity due to the plurality and diversity of industrial activity, which involves an array of actors, levels, sectors and geographical areas requiring different resources, times and structures and producing different results, impacts and feedback.

Lastly, it is essential - in order to support industrial supply chains - to ensure interoperability, in other words the ability to communicate and exchange information and functions with other systems, platforms and devices operating in the real world or the virtual world. The industrial metaverse must be able to integrate and interact with a range of sources and destinations for data and services that are key to industrial activity, such as sensors, machinery, software, applications, networks, clouds, protocols, standards, laws, authorities, partners, customers, suppliers, competitors, regulators and consumers.

5.3 The opportunities and challenges of the industrial metaverse

The industrial metaverse offers companies a series of opportunities and benefits, which can be summarised in four main categories:

- Innovation: the industrial metaverse allows companies to trial, test, validate and launch new digital products and integrated services with lower testing and prototyping costs and drastically reduced times for planning, industrialisation and market launch, thanks to the huge potential to simulate and create scenarios using "generative design" technologies, alongside collaborative open innovation platforms throughout the chain.
- Competitiveness: the industrial metaverse allows companies to optimise, automate and customise their processes of production, distribution and consumption, thus reducing costs, time, waste and errors, and increasing quality, safety, flexibility and differentiation. The industrial metaverse also allows companies to access new markets, customers, suppliers and sources

of funding, and to create and benefit from economies of scale, network and scope, increasing added value and profit margins.
- Sustainability: the industrial metaverse allows companies to reduce the environmental impact of their activities, save and efficiently use natural resources, energy and materials, forecast and manage environmental risk, adjust to climate change, and contribute to the transition to a green circular economy on the basis of carbon emissions. The industrial metaverse also allows companies to improve their social impact by promoting health, wellbeing, education, culture, social cohesion, inclusion, participation, citizenship, and respect for human rights, moral principles and the law, and to create shared value for stakeholders.
- Resilience: the industrial metaverse allows companies to address the challenges and opportunities caused by the complexity and dynamics of the economic, social and technological environment within which they operate; to anticipate and manage change, crisis, emergencies and threats, to safeguard and upgrade their capacities, functions and performance, to adapt and evolve in an agile, flexible and robust manner, and to continuously learn and innovate.

Nevertheless, the industrial metaverse also entails challenges and risks, first and foremost in terms of technology: the industrial metaverse requires companies to have infrastructure, devices, software, algorithms and high-quality data that is reliable, secure, compatible and up-to-date; they need to be able to support and manage the complexity and variety of industrial activity, protect and guarantee privacy, intellectual property and cybersecurity, and to preempt and resolve the problems, malfunctions, vulnerabilities and attacks that may arise from the use of digital technologies.

Added to these are the regulatory risks: the industrial metaverse requires companies to comply with the rules and obligations imposed by national and supranational authorities, the European Union in particular, in matters of social and environmental responsibility, the protection of consumers, workers and personal data, competition, fiscal obligations, safety, quality, traceability, certification, accounting and industrial activity, which may vary depending on the sectors, countries and markets in which they operate; these may require procedures, documentation, checks and sanctions that may limit or constrain a company's access to and operation in the industrial metaverse.

Furthermore, there are organisational risks and obstacles to consider: the industrial metaverse requires companies to adopt new organisational models and to be in a position to manage and coordinate the various activities, functions, processes and projects occurring in the industrial metaverse, integrate and harmonise the different cultures, skills, roles and responsibilities of the actors involved - employees, managers, consultants, partners customers, suppliers, regulators and consumers -, to foster and sustain the collaboration, communication,

participation, motivation, training and wellbeing of the various actors involved. Ethical repercussions also merit consideration: the industrial metaverse requires companies to respect ethical principles and values, to guarantee and foster respect, dignity, equity, transparency, responsibility and sustainability in their industrial activities, to preempt and combat any potential distortion, manipulation, discrimination, abuse and fraud that may arise from the use of digital technologies.

5.4 Applications of the industrial metaverse in ESG regulations

ESG (Environmental, Social and Governance) regulations are a series of criteria and standards that assess the performance and impact of companies in terms of environmental, social and governance sustainability. ESG regulations are increasingly pertinent and required by stakeholders such as customers, suppliers, employees, investors, regulators and society in general, who want to learn about and monitor companies' conduct and contribution to the achievement of the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement on climate change.

The ESG regulations offer challenges and opportunities for companies, which are required to adopt strategies, practices and systems that can measure, track, communicate and improve their ESG performance and impact. To this end, the industrial metaverse can offer innovative and competitive solutions, which allow companies to:

- Measure: the industrial metaverse allows companies to collect, analyse and interpret data relating to their ESG performance and impact, thanks to the use of digital twins, artificial intelligence and blockchain, which enable the creation of faithful virtual representations of their activities; view and elaborate information in real time, and verify and certify the origin and quality of data. The industrial metaverse also allows companies to compare and integrate their own data with those of other sources such as public administration, international organisations, sector associations and benchmarking platforms which provide parameters, indicators, standards and goals relating to the ESG regulations.
- Track: the industrial metaverse allows companies to monitor, control and manage their ESG performance and impact, thanks to the use of augmented and virtual reality, blockchain and the internet of things, which enable them to interact and intervene on their industrial activity, track and record the operations, transactions and modifications occurring throughout the value chain, and guarantee and demonstrate transparency, security and responsibility in their activities. The industrial metaverse

also allows companies to engage and collaborate with other actors in the ESG regulations, such as customers, suppliers, partners, regulators and consumers, who can access and participate in the industrial metaverse in order to check, validate and influence the ESG performance and impact of companies.

- Communicate: the industrial metaverse allows companies to communicate, report and disclose their ESG performance and impact, thanks to the use of augmented and virtual reality, blockchain and artificial intelligence, which enable them to create and share digital content and services that illustrate and showcase their industrial activities, supply and certify information and data relating to the ESG regulations, and generate and stimulate the interest, trust, reputation and preferences of company stakeholders. The industrial metaverse also allows companies to receive and integrate feedback and evaluations by other actors involved in the ESG regulations, who can express and share their opinions, expectations, suggestions, criticisms and acknowledgement of companies' ESG performance and impact.
- Improve: the industrial metaverse allows companies to improve, optimise and innovate their ESG performance and impact, thanks to the use of digital twins, artificial intelligence and augmented and virtual reality, which enable them to simulate, test, validate and launch new industrial solutions and practices that respond to and anticipate ESG regulations and which increase the efficiency, quality, competitiveness and sustainability of their industrial activities, creating added value and competitive advantage for the companies and their stakeholders. The industrial metaverse also allows companies to learn and innovate continuously, thanks to the possibility of accessing and benefiting from the knowledge, experience, expertise and opportunities of other actors involved in the ESG regulations, which can offer and exchange information, services, resources and collaboration in the industrial metaverse.

5.5. The industrial metaverse market: size, trends and opportunities

The industrial metaverse market is growing rapidly and showing extremely promising prospects for development, both globally and regionally. This article will analyse the size, trends and opportunities of the industrial metaverse market, with a particular focus on Europe, in comparison to other areas of the world.

5.5.1 Size of the market

The industrial metaverse market is made up of two main segments: supporting technologies, which include hardware, software and services that allow companies to create and access the industrial metaverse; and vertical applications, which include specific solutions for the various sectors and industrial fields that use the industrial metaverse.

According to Grand View Research estimates, the global industrial metaverse market was worth 82 billion dollars in 2022, and is expected to reach a total value of between 250 and 400 billion dollars by 2025, with a compound annual growth rate (CAGR) of 40%. The supporting technologies segment accounts for 60% of the market, while the vertical applications segment accounts for 40%. The former is dominated by augmented and virtual reality, which makes up 70% of the segment, followed by artificial intelligence with 20% and other technologies with 10%. The vertical applications segment is dominated by the automotive sector, which accounts for 30% of the total, followed by manufacturing with 20% and other sectors, which make up 50%.

According to estimates by Nokia-EY, the European industrial metaverse market was worth 15 million euros in 2022, and is expected to reach a value of 50 million euros by 2025, with a CAGR of 35%. The supporting technologies segment accounts for 55% of the market, with vertical applications representing 45%. The former is dominated by augmented and virtual reality, which makes up 65% of the segment, followed by artificial intelligence with 25% and other technologies with 10%. The vertical applications segment is dominated by the energy sector, which accounts for 25% of the total, followed by transport with 20% and other sectors, which make up 55%.

5.5.2 Market trends

The industrial metaverse market is influenced by a range of factors that determine its growth and evolution, both globally and regionally. The most important market trends are the following:

- Digitalisation and the digital transformation of companies, which drives them to invest in innovative technologies and solutions in order to improve their efficiency, quality, competitiveness, sustainability and resilience, and to create new business models, products, services and experiences in response to the needs and expectations of customers and stakeholders.
- The Covid-19 pandemic and its consequences, which have accelerated the process of digitalisation and digital transformation, due to the restrictions imposed by containment and prevention measures, which limited mobility, presence and communication between people and things, and stimulated the demand and supply of digital solutions that enable companies to operate and interact remotely in a secure, immersive and effective manner.

- Sustainability and social and environmental responsibility, which pushes companies to invest in technologies and solutions that enable them to reduce the social and environmental impact of their activities, save and optimise natural resources, energy and materials, preempt and manage social and environmental risk, adapt to the changing climate, contribute to the transition to a green, circular low-carbon economy and create shared value for stakeholders.
- National and supranational laws and regulations, which oblige companies to comply with rules and obligations in matters of safety, quality, traceability, certification and reporting of their industrial activities, and also their social and environmental responsibilities in terms of the protection of consumers, employees, personal data, competition and fiscal obligations, which can vary depending on the sectors, countries and markets in which companies operate, and may require procedures, documentation, verification and sanctions that may limit or condition companies' access to and operation within the industrial metaverse.

5.5.3 Market opportunities

The industrial metaverse market offers opportunities for growth and development at both global and regional level, which can be exploited by companies operating in the segments of supporting technologies or vertical applications. The main market opportunities include the following:

- The demand and supply of innovative and competitive solutions that allow companies to create and access the industrial metaverse, to trial, test, validate and launch new products, services and experiences in response to the needs and expectations of customers and stakeholders; increase the efficiency, quality, competitiveness, sustainability and resilience of their industrial activities and create added value and competitive advantage for companies and stakeholders.
- Collaboration and cooperation among actors involved in the industrial metaverse, which allows companies to interact and harmonise their activities, functions, processes and projects with those of other actors such as customers and suppliers.
- Standardisation and harmonisation of regulations and standards relating to the industrial metaverse, which allow companies to operate securely, transparently and responsibly within the industrial metaverse, comply with and implement the rules and obligations imposed by national and supranational authorities, guarantee and demonstrate quality, traceability, certification and reporting of their industrial activities, and facilitate and encourage integration and interoperability among the various systems, platforms and devices operating in the industrial metaverse.

– Education and training of users and operators of the industrial metaverse, which allows companies to develop and acquire the skills, knowledge and expertise necessary to create and access the industrial metaverse, to operate within it in an effective, efficient and immersive manner, to learn and innovate continuously, thanks to the possibilities offered by the industrial metaverse, and to access and use information, experiences and opportunities of other actors involved in the industrial metaverse.

5.6. Public policy for the industrial metaverse: how to benefit SMEs

Small and medium-sized enterprises (SMEs) are an essential part of the European economy, because they account for 99% of companies, 67% of employment and 57% of added value. SMEs are also drivers of innovation, growth and social cohesion, as they contribute to diversification, specialisation, competitiveness, sustainability and inclusion in a range of sectors and geographical areas. However, SMEs face a number of challenges and barriers which limit their ability to adapt and prosper in the economic, social and technological environment in which they operate; these include lack of financial, human and material resources, difficulties accessing markets, customers, suppliers and partners, regulatory, fiscal and bureaucratic complexity, and vulnerability to risk, crises and threats.

This article will analyse a series of public policy recommendations which could be proposed to the European Commission and, more generally, to national and European institutions to facilitate the use of the industrial metaverse by SMEs, particularly those that belong to industrial supply chains and global value chains. The recommendations focus both on encouraging the adoption of the necessary technologies, and on supporting the training and innovation needed to support digital transformation in preparation for the industrial metaverse.

5.6.1 Recommendations to facilitate the adoption of enabling technologies

Enabling technologies are those that allow the creation of and access to the industrial metaverse, such as digital twins, augmented and virtual reality, artificial intelligence, blockchain, the internet of things and cloud computing. These technologies require infrastructure, devices, software and services that are high quality, reliable, secure, compatible and updated, which can support and manage the complexity and variety of industrial activities, protect and guarantee privacy, intellectual property and cybersecurity, and preempt and solve the problems, malfunctions, vulnerability and attacks that may arise from the use of digital technologies.

SMEs often lack the financial, human and material resources they need to acquire, implement, maintain and update these enabling technologies, and also face difficulties with access, integration, interoperability, standardisation, regulation, training, assistance and support in these technologies. To facilitate the adoption of enabling technologies by SMEs, the following policy recommendations can be proposed:

- Provide financial support for SMEs for the purchase, implementation, maintenance and updating of enabling technologies by means of grants, subsidies, incentives, loans, guarantees and tax concessions; these should be appropriate for the needs of SMEs, easily accessible, transparent and simplified, coordinated and harmonised at national and European level, and monitored and assessed in terms of impact and effectiveness.
- Encourage collaboration and cooperation between SMEs and other actors in the industrial metaverse ecosystem such as large enterprises, universities, research centers, sector associations, digital platforms, technology providers and public services, so that they can offer and exchange information, knowledge, experience, skills, resources, services and collaboration relating to enabling technologies, create and enjoy economies of scale, network and scope, foster open innovation, dissemination, transferability and scalability in the enabling technologies.
- Stimulate the supply and demand of innovative, competitive solutions based on the industrial metaverse, which can respond to and anticipate the needs and expectations of the customers and stakeholders of SMEs, increase the efficiency, quality, competitiveness, sustainability and resilience of industrial activities carried out by SMEs; create added value and competitive advantage for SMEs and stakeholders through the promotion, circulation, dissemination, demonstration, validation, certification and prioritisation of solutions based on the industrial metaverse.
- Facilitate standardisation and harmonisation of the laws and standards relating to the enabling technologies, so that they ensure and guarantee the quality, security, compatibility and updating of the technologies in order to facilitate and encourage integration and interoperability among the different systems, platforms and devices operating in the industrial metaverse; comply and adapt to the rules and obligations imposed by national and European authorities relating to the privacy, intellectual property, cybersecurity, social and environmental responsibility, protection of consumers, employees and personal data, competition and fiscal obligations of industrial activities.

5.6.2 Recommendations to support organisational training and innovation

Organisational training and innovation are practices and processes that allow companies to acquire and develop the necessary expertise, skills and abilities to create and access the industrial metaverse, to operate and interact in an effective, efficient and immersive manner within the industrial metaverse, and to learn and innovate continuously, thanks to the possibilities of the industrial metaverse.

Organisational training and innovation require strategies and systems that can manage and coordinate the various activities, functions, processes and projects operating in the industrial metaverse in order to integrate and harmonise the different cultures, skills, roles and responsibilities of the actors involved, such as employees, managers, consultants, partners, customers, suppliers, regulators and consumers; foster and support the collaboration, communication, participation, motivation, training and wellbeing of the various groups.

SMEs often lack the financial, human, material and organisational resources they need to develop the skills, knowledge and competence necessary in order to create and access the industrial metaverse, and they also need to address various difficulties related to adaptation, learning, innovation, change, culture, leadership, management, engagement, training, assistance and support for organisational training and innovation. To facilitate organisational training and innovation by SMEs, the following policy recommendations can be proposed:

- Train and qualify the human resources of SMEs for the industrial metaverse through programs, courses, pathways and certifications that are appropriate for the needs and capacities of SMEs and easily accessible, transparent and simplified, coordinated and harmonised at national and European level, monitored and assessed in terms of impact and effectiveness, and centered on the acquisition and development of the expertise, knowledge and skills necessary to create and access the industrial metaverse, operate and interact in an efficient, effective and immersive manner in order to learn and innovate continuously, thanks to the possibilities offered by the industrial metaverse.
- Innovate and transform the organisational models of SMEs for the industrial metaverse by means of advice, assistance and support geared to the needs and capacities of SMEs, which should be easily accessible, transparent and simplified, coordinated and harmonised at national and European level, monitored and assessed in terms of impact and effectiveness, and centred on the development and implementation of strategies, practices and systems that are able to manage and coordinate the various activities, functions, processes and projects operating in the industrial metaverse; able to integrate and harmonise the different cultures, skills, roles and responsibilities of the various actors involved and to foster and sustain

the collaboration, communication, participation, motivation, training and wellbeing of the various actors involved.

– Create and exploit the opportunities for learning and innovation offered to SMEs by the industrial metaverse through the promotion, communication, circulation, demonstration, validation, certification and rewarding of good practices, success stories, experiences, expertise and opportunities relating to organisational training and innovation in the industrial metaverse, so that these will stimulate and encourage SMEs to invest in and commit to organisational training and innovation in the industrial metaverse, and create and strengthen networks, communities and ecosystems of learning and innovation between SMEs and other actors involved in the industrial metaverse.

5.7 Conclusions

The industrial metaverse is an emerging and fast-evolving reality, which offers industrial companies a series of opportunities and benefits, but which also brings challenges and risks that require the adoption of appropriate and innovative strategies, practices and systems. SMEs are an essential part of the European economy which can benefit greatly from the industrial metaverse, but which must face challenges and barriers that limit their capacity to adapt and prosper in the economic, social and technological environment in which they operate. To facilitate use of the industrial metaverse by SMEs, a number of policy recommendations can be proposed, focusing on both encouraging the adoption of enabling technologies, and support for the organisational training and innovation necessary to support companies' digital transformation in preparation for the industrial metaverse.