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Achieving Digital Supply Chain with Adopting Metaverse

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Abstract

Metaverse has a wide range of application scenarios in the social and economic fields and has played an important role in promoting the innovation of human thoughts and ideas. Metaverse has brought about reconsideration and transformation in production, entertainment, and supply chains. In this paper, first, the origin of the metaverse and its related technologies, such as Artificial Intelligence, Cloud computing, IoT, Human Computer Interaction and Digital twins are discussed, especially in relationship to blockchain technology and NFTs. In addition, this paper analyzes the potential application of the metaverse in the supply chain and proposes a conceptual framework for a supply chain digital ecosystem with the metaverse. Finally, the case of building a metaverse in the Japanese automotive industry is demonstrated. Furthermore, through analysis of the connotations of the metaverse, this paper proposes that the metaverse is not equal to the virtual world, nor is it another form of existence parallel to the real world, but a form of interaction and integration of the real world and the virtual world, which is the living and working environment of human beings in the future.

Keywords: *metaverse, supply chain digital ecosystem, AIGC, blockchain, NFT*

1. INTRODUCTION

The concept of Metaverse originated from Neal Stephenson's science fiction novel, "Snow Crash," which describes a world in which people interact with various software in a multi-dimensional space as digital identities (Stephenson, 1992). Prior to this, American mathematician, computer expert and author, Professor Vernor Vinge, in his novel, "True Names" conceived a virtual world that could be accessed through a brain-computer interface which obtains sensory experience (Vinge, 1981). Since then, concepts similar to the Metaverse appeared in other novels under various names. Furthermore, about 10 years after the publication of "Snow Crash," the MMORPG (massively multiplayer online role-playing game) "Second Life" launched in 2003, which took players into a world where they could actually experience and feel the Metaverse (Jeffery & Collins, 2008). Today, in a MMORPG "Roblox," people can build houses, socialize, and even earn currency and use it in real

life. Likewise, characters in the sci-fi movie, "Ready Player One" can purchase equipment in the virtual world "Oasis" and then receive the goods offline. Both of these examples highlight the typical characteristics of the Metaverse as a new world where the virtual world and the real world are superimposed and co-exist.

The word "Metaverse" consists of two parts: Meta- and -verse: Meta- means transcendence and -verse means universe, which together translate literally as "transcendence universe," meaning a digital space that runs parallel to the real world (Wright et al., 2008). The Metaverse is integrated with the real world through technologies such as Virtual Reality (VR), Augmented Reality (AR), and eXtended Reality (XR) to form a world of virtual-real mapping, real-time connection, and dynamic interaction (Barrera & Shah, 2023). At present, there are different opinions on the definition of the concept of the metaverse, but in this paper, we temporarily define it as follows: a virtual world that is linked and created by technological means, mapped and interacted with the real world, a digital living space with a new social system, and its essence is the process of virtualizing and digitizing the real world.

From the perspective of the development of the Internet, that is, from the local area network (LAN) to the wide area network (WAN), to the mobile Internet, and then to the blockchain known as the "Internet of Value," users' sense of participation and immersion has gradually increased (Kinsner, 2021). With the continuous improvement of infrastructure such as 5G, the Internet of Things (IoT), blockchain, and Artificial Intelligence (AI), and the continuous development of technologies such as VR/AR/XR, Cloud computing, and Digital twins, the next singularity of the human information technology revolution is approaching (Sun et al., 2022). At the same time, the Metaverse is a significant topic in the face of the spread of worldwide epidemics and the intensification of disasters such as regional wars, by changing the existing ways and concepts of production, living, learning, and communication to create a sustainable and resilient new society. Therefore, the ecosystem architecture of the Metaverse is a significant issue.

In this paper, the core technology status of blockchain in the metaverse is explained from four aspects: 1) how blockchain realizes the infrastructure of the metaverse, 2) how blockchain provides an identity value network in the virtual world, 3) how blockchain builds an economic and financial system, and finally, how blockchain builds a trusted digital value interaction network in the metaverse. Moreover, through the discussion and comparison of technologies such as Digital twin and Human Computer Interaction in this paper, we show how the metaverse provides a completely new framework for the digital reorganization of the entire supply chain system from R&D to customer service. Finally, through an analysis and study of a particular case in Japan's automobile industry, this paper shows how supply chain companies cooperate to build a metaverse system and use this system in improving supply chain resilience.

2. THE CONCEPT OF METAVERSE AND RELATED TECHNOLOGIES

The industry has not formed an authoritative definition. However, there is a basic consensus that the Metaverse is the integrated application of a new generation of information technology (such as the Internet of Things, artificial intelligence, blockchain, human-computer interaction, etc.) in the entire life cycle of the industrial field (Kanematsu et al., 2014). The Metaverse comprehensively maps each link in the physical world, such as R&D design, manufacturing, logistics, marketing, product service, etc., in a virtual space. Through real-time dynamic interaction between digital space and physical space, a brand-new R&D, manufacturing, and service system will be constructed to realize the improvement of quality, cost reduction, increases in efficiency and model innovation in supply chains, that will drive industrial manufacturing to transition to a new energy level platform, and to achieve high quality development (Jeong et al., 2022).

Dionisio et al. (2013) summarized four technical characteristics of the core components of the metaverse, including authenticity, ubiquity, interoperability, and scalability. Authenticity requires the virtual space to be realistic enough to make users psychologically and emotionally immersed in the virtual space. Ubiquity requires that the virtual

spaces that make up the metaverse are accessible through all existing digital devices (desktops, tablets, mobile devices) and that users' virtual or collective identity can be achieved through these devices. Interoperability requires that virtual spaces conform to standards so that the digital assets used to recreate or render virtual environments remain interchangeable in specific implementations, where users can move seamlessly between locations without disrupting the immersive experience. Scalability requires a server architecture that provides enough power to enable a large number of users to occupy the metaverse without affecting system efficiency and user experience.

Eno et al. (2009) built a content collection system based on 3D multi-user virtual worlds, which can be used for cross-world search engines to connect virtual worlds with wider networks. In addition, the authors wrote intelligent agent crawlers that crawl user-generated content, which improve researchers' ability to identify dynamic, immersive environments within the world. Eglisston et al. (2021) believe that VR is a data-intensive device that creates a users' immersion in the virtual environment through auditory, visual, and tactile feedback.

Cheslack-postava et al. (2012) designed and implemented the Sirikata server for the metaverse. The scalability of the Sirikata server can support large and complex world modeling, allowing users to view and interact with the entire world, while simultaneously achieving both goals by leveraging properties of the real world and a 3D environment in the core system, such as a new distributed data structure that serves virtual object queries based on the visible size.

Sebastien et al. (2009) believed that the metaverse could realize the three-dimensional representation of the immersive virtual world and support the establishment of an information system to identify and help manage biodiversity. This research investigated the different possibilities of meta-spaces for storing information in biodiversity-specific information systems and introduced the general process of virtual world generation, requirements, different models of metadata structure, and metadata that can be used to improve the level of detail.

Ryskeldiev et al. (2018) proposed and implemented a blockchain-based distributed model that can be used for peer-to-peer archiving, recycling, and sharing of virtual spaces for social and collaborative applications in mixed reality. Moreover, this blockchain can be used as an alternative source of spherical imagery for mixed reality spaces in map applications, allowing the entire meta-space to be stored in a JSON array for easy storage and sharing as plain text.

Whether performing computationally heavy tasks remotely, accessing large databases, or providing shared experiences between users, networking and communication are essential. The immersive experience required in the metaverse system requires the network to have characteristics such as low latency, large bandwidth, and high reliability (Slalmi et al., 2021). The new generation of information infrastructure, 5G, the fifth generation of mobile communication technology, has an Internet access rate of up to 1Gbps and a latency as low as 1ms, which can fully meet the performance indicators of the Metaverse, and at the same time provide an important network foundation for the application of the Metaverse (Muheidat et al., 2022). However, the current 5G technology still has some deficiencies, which affect the user experience of metaverse applications, such as signal interference and network congestion in complex environments. Concurrently, 6G is being developed, and the transmission capacity of 6G may be 100 times higher than that of 5G, so that the network delay may also be reduced from milliseconds to microseconds (Xu et al., 2022). The future 6G network will be a fully connected world integrating terrestrial wireless and satellite communications. 6G technology is no longer a simple breakthrough in network capacity and transmission rate, but a network that narrows the digital divide and realizes the interconnection of everything. With the gradual maturity and commercial application of 6G technology, the interaction delay between the Metaverse and the physical world will be greatly reduced, and the users' perception and experience in the Metaverse will be significantly improved.

On the other hand, numerous instances of failure and potential problems have been observed in the construction and implementation of the metaverse. The following factors can be considered

as contributing to these challenges:

- Technological limitations: Current hardware and software capabilities have not yet reached the level required to create a fully immersive, seamless, and scalable metaverse experience (Raad and Rashid, 2023).
- Interoperability constraints: The lack of standardized protocols and platforms has resulted in fragmented virtual environments that are unable to communicate or integrate effectively.
- User experience deficiencies: Many existing metaverse attempts have failed to provide compelling, intuitive, and engaging user experiences.
- Privacy and security concerns: The collection and processing of vast amounts of personal data within metaverse environments raise significant privacy and security issues.
- Economic viability: The development and maintenance of metaverse infrastructures require substantial financial investments.
- Social and cultural barriers: The concept of a metaverse challenges traditional notions of social interaction and cultural norms.
- Regulatory uncertainties: The lack of clear regulatory frameworks governing metaverse environments has created legal ambiguities and potential liabilities for developers and users alike.
- Content creation limitations: The development of engaging, diverse, and high-quality content for metaverse environments requires significant resources and specialized skills.

As a relevant case study, the failure of Meta's substantial investment in the Metaverse, despite the allocation of billions of dollars. Several factors can be posited to explain this outcome (Kraus et al., 2022). Primarily, Meta's approach has been criticized for being overly centralized and corporate-driven, which contradicts the decentralized and user-centric vision many associate with the Metaverse concept. Additionally, the company's focus on VR technology as the primary interface has limited accessibility and appeal to a broader user base, given the current limitations of VR hardware and associated discomfort issues.

Furthermore, Meta's Metaverse offerings have struggled to provide compelling use cases and content that justify widespread adoption, particularly in the face of existing, more accessible social media and communication platforms. The company's approach has also raised significant privacy concerns, given its history of data management issues, further deterring potential users and stakeholders.

In the interaction between the virtual world and the real world, the interaction between users, and the operation of metaverse applications, an inestimable mass of data will be generated, all of which require the support of cloud computing (Thomason, 2022). The supporting role of cloud computing for metaverse applications is mainly reflected in data processing and data storage. When performing some computationally heavy tasks, due to the limited computing power of terminal devices, Metaverse applications also need to rely on the powerful computing power of the cloud computing platform to achieve efficient processing of big data. At the same time, due to the limited storage capacity of terminal devices, massive data requires a cloud computing platform to realize distributed storage. In recent years, with the continuous development of cloud computing technology, the cloud provides the underlying technical support for the landing application of Metaverse.

The ubiquitous connection between the virtual world and the real physical world under the framework of the Metaverse requires numerous sensors, smart terminals, and other IoT devices to provide support for data collection, processing and transmission (Cerasa et al., 2022). Therefore, IoT technology is the technical basis for virtual-real interaction and the interconnection of all things in the metaverse, and IoT is an information bridge for the communication and connection between the virtual world and the real world. The further development of computer hardware and the IoT technology will promote the miniaturization and portability of virtual terminal devices, so that users can access the metaverse anytime and anywhere as long as they use corresponding smart terminal devices, thus breaking the constraints of time and geographical space, can also bring users a better experience (Yang et al., 2022).

Human-computer interaction technology, mainly including virtual reality technology, augmented reality technology, and mixed reality technology (Yin et al., 2020). is one of the most important technologies in metaverse applications. At present, the most common way for users to experience the virtual world of the metaverse is to use VR glasses to integrate with the virtual space in terms of vision and hearing. Today, the relevant technologies involved in virtual reality head-mounted display devices are relatively mature, and virtual reality terminal devices have also been popularized in the consumer market (Vishwarupe et al., 2022). With the popularity of the metaverse concept, the research on human-computer interaction technology such as virtual reality is also continuously in-depth.

Digital twin is a simulation process that makes full use of physical models, sensor updates, operation history, etc., integrates multi-disciplinary, multi-physical quantities, multi-scale, and multi-probability simulation processes, and completes the mapping in virtual space to reflect the entire life cycle of the corresponding physical equipment (Magnanini et al., 2021). In short, digital twin is the process of using computer technology to digitally replicate the real world. Based on the characteristics of digital twin technology that can simulate the physical world virtually, users can realize the virtual-real interaction between the metaverse and the real world. It can be said that the digital twin is the basis for constructing the Metaverse and the core technology for realizing the Metaverse (Lv et al., 2022).

3. THE DEVELOPMENT OF AI AND THE INFLUENCE TOWARD TO METAVERSE

As the most important core technology of the Metaverse, AI's importance is self-evident. When people enter the metaverse, they exist and act as digital avatars, and avatars cannot activate without AI technology in terms of vision, hearing, touch, etc., such as AI-driven computer vision, natural language processing, digital touch, etc., with a practical landing application (Hwang & Chien, 2022). Based on massive amounts of data, AI technology conducts model training to obtain the minimum loss, so that the output value of the neural network is constantly approaching the real value, so as to achieve the accuracy required for classification or prediction tasks. Empowering the Metaverse with AI technology can improve and optimize the performance of metaverse applications to a certain extent (Cheng et al., 2021).

On the other hand, with the release of ChatGPT by OpenAI in November 2022 as a landmark milestone, Generative AI and the AIGC (Artificial Intelligence Generated Content) innovation wave it triggered quickly swept the world. Different from the existing "Analytical AI," generative AI is based on training algorithms such as autoregressive models, generative adversarial networks (GANs), variational autoencoders (VAE), flow models, diffusion models, and technologies such as training architectures represented by Transformer, starting from natural language processing and human-computer conversation (Wilkins, 2023). According to the understanding of human user needs and the aggregation processing of related content in the large-scale knowledge model dynamically constructed by itself, it is able to generate text paragraphs, images, audio and video, 3D models, program codes, and media content for specific data types such as molecular structures.

Although in some views of the public, metaverse and generative AI are two different, even mutually exclusive and alternative fields of innovation. However, the fact is that there is a close relationship between the two characteristics (Kshetri & Dwivedi, 2023). As a huge technological integration, one of the important supporting technical fields of the Metaverse is artificial intelligence and generative AI is also difficult to break away from the immersive virtual-real symbiosis environment pointed to by the metaverse (Zhan, 2022). Since the latter represents the main direction of future information products and technological products' experience evolution that people currently convinced. As a manifestation of the interaction between the two, generative AI will be able to provide support for the creation of a huge number of digital models and other content required in the metaverse environment, while the continuous innovation and wide application of the metaverse will provide generative AI with new application scenarios and user energy.

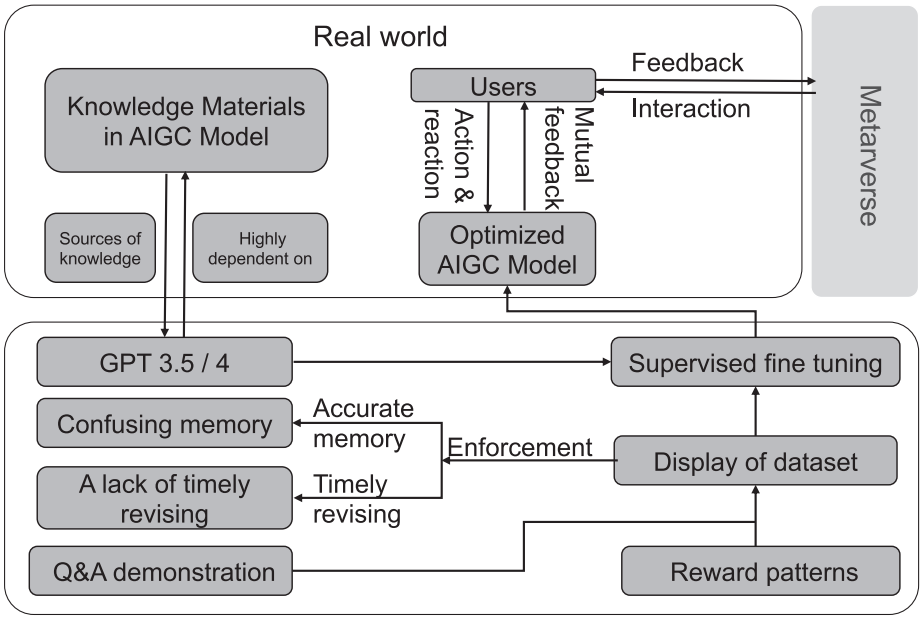

Figure 1: A simplified framework of AIGC

Source: Created by the authors

The information processing activities in which human individuals understand the objective world through activities such as sensation, perception, thinking, memory, and imagination is called "cognition" (Siemens et al., 2022). Cognition is the basis and origin of the interaction between humans and things, and it is also the ability and tools that humans, as intelligent species, must rely on to survive in the world. The immersive virtual reality symbiosis environment and multimodal embodied interactive experience built by the metaverse, as well as the content impact and feedback formed by generative AI and AIGC, continue to act on human users, and it has a great impact on human perception and thinking (Ortiz, 2023). The changes it has brought to human beings in terms of perception and thinking cannot be ignored, and the accumulation of these changes has formed a cognitive reshaping effect that accompanies the widespread application of metaverse and generative AI (see Figure 1).

4. A CONCEPTUAL STRUCTURE OF METAVERSE

Among the many elements that make up the metaverse, a fair economic system is the core driving the operation of the metaverse, and blockchain plays an important role in it. The essence of the metaverse is a virtual society based on the Internet (Karame & Capkun, 2018). In the metaverse, all aspects of the creation, exchange, and consumption of digital products can be carried out in the digital space, and people can complete a full range of experiences from games, creation, entertainment, display, social interaction, and transactions in the digital space, where the immersion and engagement have reached new peaks (Bhattacharya et al., 2016). Therefore, the trust system constructed by the blockchain is the infrastructure of the metaverse and the foundation of the metaverse economic system (Lu et al., 2019). Only by building a fair economic system can all participants be treated fairly and get rewards. Security and rules are the basis for ensuring the operation of the metaverse, including individual privacy security, institutional data and network security, etc.

By analyzing the technical characteristics of blockchain and the ecological logic of the metaverse, the implementation structure of the metaverse is divided into four layers: a meta-network, meta-system, meta-platform and a meta-space, as shown in Figure 2.

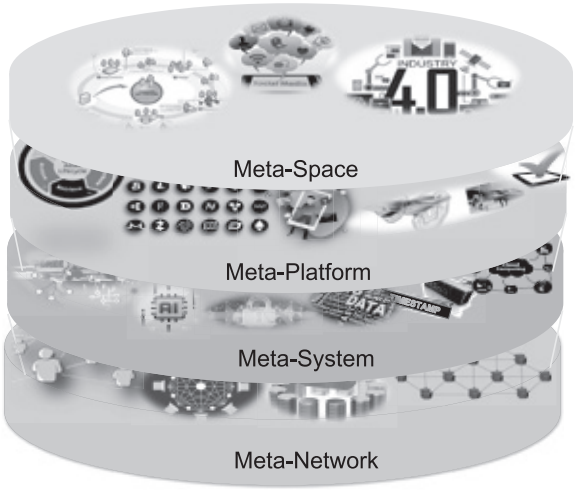

Figure 2: The implementation structure of metaverse

Source: Created by the authors

The Meta-network is the base for the operation of the Metaverse, and includes supporting technologies such as communication, storage, computing, and network. The peer-to-peer communication, distributed storage, distributed computing and distributed network of blockchain provide the underlying infrastructure for the Metaverse. The Meta-system is centered on the digital signature, timestamp service, consensus mechanism, encryption algorithm and distributed ledger of the blockchain, providing system support for the metaverse. The Meta-platform layer is mainly supported by the meta-system and provides support for Meta-space scenarios. Blockchain-related functions such as cryptographic token, digital assets, and identity authentication provide core support for the metaverse's economic system. Moreover, it is necessary to integrate technologies such as content generation, simulation, and environment rendering to provide support for immersive experiences. The Meta-space is mainly supported by Meta-network, system and platform, providing (business) clients with the best solutions for their requirements, such as industrial manufacturing, social and entertainment, e-commerce, and human-computer interaction.

5. BASIC CHARACTERISTICS AND FUNCTIONS OF BLOCKCHAIN

Looking forward to the future, the application scenarios of Metaverse will cover the entire supply chain process from R&D to after-sales service, guiding and promoting business process optimization and efficiency improvement from virtual to reality. The following points (I-IV) focus on several parts, such as R&D design, production optimization, equipment operation and maintenance, product testing, and specifically describe and demonstrate the application scenarios and expected synergy effects of Metaverse in the supply chain (Dunphy & Petitcolas, 2018).

I. Compared with product design using industrial software, R&D design under the application of the Metaverse- related technologies will improve product development efficiency and reduce product development costs to a greater extent. In terms of product design, the environmental factors during product application can be controlled through the meta-space and based on the product model designed in the meta-space, an intuitive and accurate simulation of the function of each component of the product can be made, which can effectively verify product performance. In terms of collaborative design, the Metaverse can break geographical restrictions and support multi-party collaborative design. Users can also participate in product design and experience the designed products on the meta-space. In terms of user experience, product development on the meta-space has been deeply involved with users, which is closer to user needs and can enhance user experience to a greater extent.

II. Through the meta-space, the person in charge can immersively experience the construction and operation process of a virtual smart factory, interact with the equipment and production lines in the virtual smart factory in real time, and optimize the production process and carry out intelligent production scheduling more intuitively and conveniently. In the early stage of smart factory construction, the meta-space can be used to build a virtual smart factory that is consistent with the building structure, production line layout, production process, and equipment structure of the real smart factory, so as the rationality of production

capacity configuration, equipment structure, personnel movement and other aspects can be verified in advance.

III. Compared with the current predictive maintenance using big data analysis, the equipment operation and maintenance based on the metaverse can break the space limitation and effectively improve the response efficiency and service quality of equipment operation and maintenance. In the meta-space established by the meta-space, operations and maintenance personnel will not be restricted by regions. When there is a problem with the production equipment, they can remotely confirm the equipment condition in real time and repair the problem in time. For difficult and complex equipment problems, experts from all over the world can be gathered through the meta-space to discuss solutions together, thereby improving production efficiency.

IV. For products with high application standards and complex testing requirements, the Metaverse can provide a virtual environment for experimental verification and product performance testing. Through the combination of virtual and reality, the simultaneous testing of physical space and virtual space can be realized, and the internal and external changes of the product can be more intuitively detected, and the efficiency and accuracy of test certification can be improved. Compared to civilian consumer-grade chip products, automotive grade AI chips have complex functional designs due to changing working environments and high safety requirements. Therefore, their R&D, testing, and certification processes are very strict, and they need to meet a number of international and domestic industry standards. The Metaverse can provide a virtual test space for automotive-grade AI chips. Engineers can test automotive-grade AI chips at a lower cost. Also, they can simulate and experience self-driving cars equipped with AI chips, improving the testing and certification efficiency of automotive-grade AI chips.

While blockchain technology presents certain challenges, its unique properties offer distinct advantages that may outweigh its limitations in the context of metaverse development. Firstly, blockchain technology provides a decentralized and trustless environment, which is fundamental to the vision of an open and user-controlled metaverse. Secondly, blockchain's immutability and transparency features are crucial for maintaining the integrity of digital assets, ownership records, and transaction histories within the metaverse. Thirdly, the programmability of blockchain through smart contracts enables the creation of complex, self-executing agreements and interactions within the metaverse without the need for intermediaries.

However, the challenges associated with blockchain technology, particularly the blockchain trilemma of scalability, security, and decentralization, cannot be ignored. Recent advancements in blockchain technology, such as layer-2 solutions, sharding, and consensus mechanism innovations, are addressing these limitations (Kaur and Gandhi, 2020). These developments suggest that the trade-offs between scalability, security, and decentralization may become less pronounced in the future. It is worth noting that the use of permissioned databases or other open-source databases may be appropriate for certain aspects of metaverse infrastructure, particularly where high transaction throughput and low latency are critical. A hybrid approach, combining the strengths of blockchain technology with other database solutions, may provide an optimal balance of performance, security, and decentralization.

6. UTILIZATION OF NFT AS CRYPTO ASSETS IN METAVERSE

Before the metaverse, the virtual economy was relatively fragmented and completely attached to the real world. The formation of a virtual parallel world had a relatively feasible landing path until the concept of the metaverse was born. Although the metaverse is closely related to the real world, it still maintains a certain degree of independence; meanwhile, the metaverse with digitization as its basic feature is a relatively decentralized and inclusive system.

There are two main streams for the development of the metaverse in the asset dimension: First, existing assets, namely equity, bonds, gold and other assets; The second is digital native assets in the development of Non-Fungible Token (NFT). The important feature of NFT is that each NFT has a

unique identifier, and two are not interchangeable. Moreover, the minimum unit is one and indivisible. Therefore, it is very suitable for the tokenization of exclusive and indivisible rights and assets, and can also be freely traded and transferred.

Traditional digital identities emphasize the mapping and bundling of individuals from the real world to the virtual world. The NFT digital asset certificate supported by blockchain and distributed ledger technology further assign the attributes of identity to arbitrary data and assets, which can not only realize the interconnection of all things and value generation in the metaverse ecology, but also fully consider privacy. An NFT can permanently save transaction history on the blockchain, thus ensuring the uniqueness of digital assets. Each token has a unique identifier, which enables it to authenticate digital assets.

Each token has a unique Token ID, which verifies the ownership of digital assets. In a 3D space such as the metaverse, social and economic activities operate like reality, and relevant technologies are needed to realize asset ownership certification and value exchange. NFT supports the mediation and interaction between transaction parties in the metaverse, thus its development has been rapid in the metaverse. With NFT as a tie, the metaverse can establish a set of social contracts for the virtual world. Due to the uniqueness and indivisibility of NFT, participants in the metaverse can effectively claim their copyright and ownership.

7. A CONCEPTUAL FRAMEWORK OF SUPPLY CHAIN DIGITAL ECOSYSTEM WITH METAVERSE

Digital technologies such as AI and blockchain are reshaping the boundaries and operating modes of the economy and society, and more participants are involved, especially as consumers on the demand side are absorbed into the digital supply chain and become a new driving force (Grassi et al., 2022). The development of information technology has sharply enhanced the importance of knowledge and information in the production and operation of enterprises, and the network collaboration between supply chains has been paid more attention. The digital supply chain transforms the competitive strategy from the traditional supply chain based on product/service to the digital supply chain ecosystem based on the industrial network. The network characteristics of the digital supply chain make the value capability research in enterprise management shift from the upstream and downstream relationship of the supply chain to the network relationship composed of actors and resource elements.

In the digital supply chain system, the value relationship between subjects is no longer a linear relationship between upstream and downstream, but a network (peer-to-peer) relationship composed of different subjects (nodes). On the other hand, the Metaverse is not a technology, but it condenses almost all of today's most cutting-edge digital technologies. Therefore, the Metaverse will become the biggest driving force behind the development of digital supply chains to intelligent supply chains, and it will also quickly transform the static mode of the traditional supply chain into a dynamic ecological mode in which all parties in the supply chain interact at any time (Mourtzis et al., 2022).

During the design and development process of products and materials, the supply chain metaverse ecosystem can provide environmental factors that can control the application of products. And based on the product model designed in the metaverse system, it makes an intuitive and accurate simulation of the function of each component of the product, so that it can effectively verify the performance of the product. In terms of collaborative design, the supply chain metaverse ecosystem can break through geographical restrictions and support multi-party collaborative design, so that users can also participate in product design and experience the products they design in the metaverse system. In terms of user experience, product development in the supply chain metaverse ecosystem, through the deep participation of clients, is closer to clients' needs and can enhance clients' experience to a greater extent (see Figure 3).

In terms of production and manufacturing, through the supply chain metaverse ecosystem, the staff can experience the construction and operation process of the virtual smart factory immersively and interact with the equipment and production lines in the virtual smart factory in real time, which

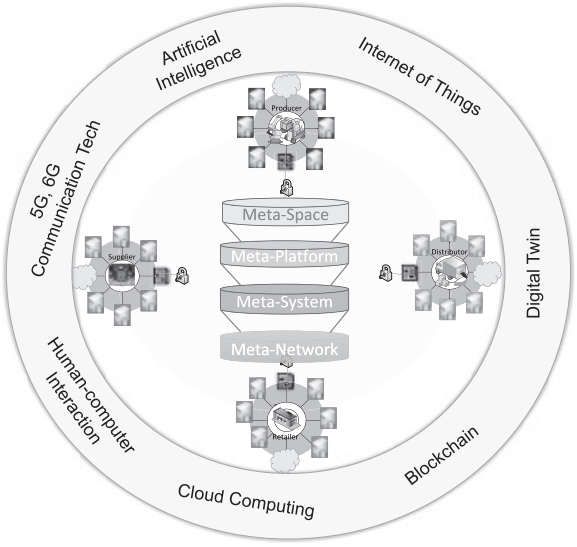

Figure 3: A conceptual framework of digital ecosystem with metaverse

Source: Created by the authors

can optimize production more intuitively and conveniently process and carry out intelligent production scheduling. In the early stage of smart factory construction, the supply chain metaverse ecosystem can be used to build a virtual smart factory that is consistent with the architectural structure, production line layout, production process, and equipment structure of the real smart factory, so that it can realize a reasonable verification in advance such as production capacity configuration, equipment structure, and personnel. For any changes in the production process of intelligent manufacturing, it can be simulated in the supply chain metaverse ecosystem to predict the production status and realize the optimization of the production process.

Compared with the current predictive supply using big data analysis, the supply chain metaverse ecosystem's supply model can break through space constraints, effectively improve the efficiency of supply response and the quality of supply in emergencies. In the virtual space established by the supply chain metaverse ecosystem, transportation personnel will not be restricted by region. When problems occur during transportation, the ecosystem can realize remote real-time confirmation of the product and customers' situation and solve the problem in time. For difficult and complex emergencies, experts from all parties can be brought together through the supply chain metaverse ecosystem to discuss solutions, thereby improving supply efficiency and safety, as well as customer satisfaction.

For high-uncertainty markets with high application standards and complex user requirements, the supply chain metaverse ecosystem can provide diverse and real-time dynamic scenarios, allowing decision makers and relevant personnel to quickly and accurately grasp various possibilities and the resulting consequences influence to make the best judgment. Moreover, through the combination of virtual and real to realize the simultaneous testing of physical space and virtual space, the staff can feel the internal and external changes of various market conditions more intuitively and improve the efficiency and flexibility of decision making and collaborative work.

8. A CASE STUDY IN AUTOMOTIVE INDUSTRY INVOLVED WITH METAVERSE

Technological innovation is advancing in the world of three-dimensional maps, which are indispensable for autonomous driving. In Japan, the Dynamic Map Foundation (DMP) was established in 2017 with the aim of producing 3D maps for autonomous driving and Advanced Driver Assistance Systems (ADAS). In addition to the public-private fund INCJ (Innovation Network Corporation of Japan), Japan's leading automotive manufacturers, M Corp and Z Ltd are jointly investing in development under an all-Japan framework. A combination with the metaverse is also being considered. The detailed location information that 3D maps can use to reproduce the real world in a virtual space, design buildings, simulate transportation networks can be used as an index in the virtual space, thus become a great value.

Japanese automobile manufacturer A Company has been conducting a demonstration for proving the value of a vehicle and transferring the ownership using the same idea as NFT. This means building a metaverse mainly around their own products based on blockchain technologies, incorporating concepts, such as NFT and smart contracts, working with supply chain members. Moreover, the

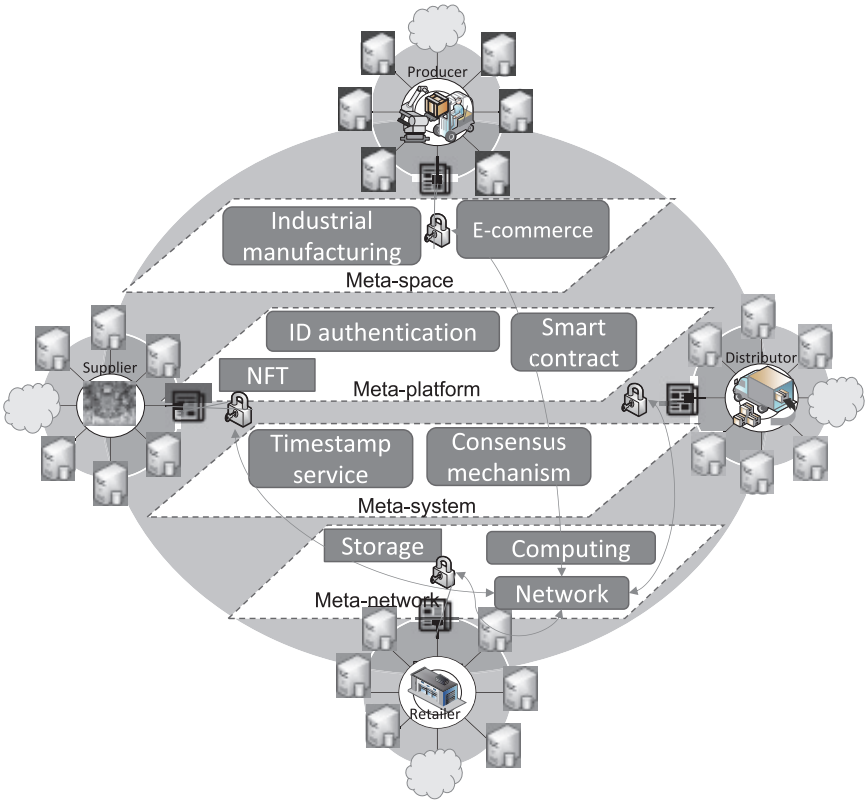

Figure 4: A simplified model of metaverse in Japanese manufacturing industry

Source: Created by the authors

company can provide consumers with experience services such as simulation in-store consultation, test drive or interior modification by meta-space (see Figure 4).

At present, the concept of Metaverse is still in the early stages, and the concept still needs more optimization and innovation in terms of computing power, VR/AR and other technologies. For the automotive industry, although various professional and technical barriers across the Internet will hinder the speed of integrating the concept of the metaverse, as many more emerging companies enter the automotive industry through cross-border integration, automotive products are gradually becoming a new generation of interactive terminals. On the basis of intelligent development, firms continue to introduce new business models that integrate the concept of metaverse and the characteristics of automotives. Whether it is the improvement of quality and efficiency in industrial production, or the inspiration of new business models, it is proving that the concept of metaverse has high reference value for the future development of the automotive supply chain.

From the aforementioned case study, several insights can be derived regarding the potential efficacy of Metaverse systems in Japanese manufacturing and supply chain management.

- Focused application: Unlike general-purpose virtual workspaces, a metaverse system for manufacturing would be tailored to specific industry needs, potentially offering more immediate and tangible benefits.
- Existing digital infrastructure: Japanese manufacturing firms often have advanced digital systems in place, providing a foundation for metaverse integration.
- Cultural alignment: The Japanese business culture's emphasis on collaboration and

continuous improvement aligns well with the potential of metaverse technologies to enhance communication and process optimization.
- Supply chain complexity: The intricate nature of global supply chains in manufacturing necessitates advanced visualization and simulation tools, which metaverse technologies could provide.
- Industry 4.0 initiatives: Japan's push towards Industry 4.0 creates a conducive environment for adopting advanced technologies like the metaverse in manufacturing contexts.

9. CONCLUSIONS

The Metaverse is the reproduction and extension of the physical world in the digital virtual world. It unifies the physical world and the transformed virtual world in the digital field. It is also a digital world characterized by technology integration, real-time interaction, physical immersion and combination of virtual and real worlds. Looking forward to the future, the metaverse will continue to develop under the interaction of technology iteration, market expansion, and application requirements, while new technologies, new products, new models, and new formats will continue to grow under the concept of the Metaverse. At present, the development of the Metaverse has only taken the first step.

The research and practices of the Metaverse still needs to further find application scenarios and innovative solutions in terms of identity, economic mechanism and economic model in years to come. For instance, as mentioned in the use case of this paper, in the digital space, by casting car NFT as proof of ownership, the IoT is used to collect data on the entire life cycle of vehicles. It is bound to the car NFT for product development and design, as well as user personalized service formulation, etc. However, the project is still in the proof-of-concept stage, and it will take some time before it is officially launched. Based on the integration of technologies such as digital twins, artificial intelligence, and blockchain, XR, 5G (6G) networks, Metaverse reshapes supply chains in the digital space, thus providing human society with the combination of virtual and real products that are currently unimaginable.

As the continuous improvement of the Metaverse environment, the niche and expansion of customers demand will become more obvious. Against such a background, as stated in the paper, the rise of the digital supply chain attached to the metaverse will allow producers to participate in production activities such as product planning, product design, and product development in an immersive way. At the same time, it helps supply chain operators eliminate the space-time gap between participants, thereby creating a real digital business ecosystem, and opening up a new track in the digital economy.

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