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THE INDUSTRIAL METAVERSE REPORT

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THE INDUSTRIAL METAVERSE REPORT

ABSTRACT

In March 2021, with the listing of Roblox, the first stock in the Metaverse concept, the Metaverse has attracted global attention. Facebook, Microsoft, NVIDIA, Tencent, Byte Dance, Baidu, and others have all laid out related fields. The Metaverse is a new generation of internet applications and social ecology built on new infrastructure that integrates virtual worlds with the real world. Through technologies such as blockchain, artificial intelligence (AI), augmented reality (AR), and digital twins, the Metaverse achieves mirror mapping of the real world, expands time and space boundaries, and extends value to help people realize their digital identities in virtual worlds and achieve integration between virtual and real worlds through means such as AR.

The Industrial Metaverse is an important application area within the Metaverse. It is a new industrial system, economy, and model serving the industrial economy based on core infrastructure and application concepts of the Metaverse. The Industrial Metaverse can achieve holographic display and cross-time–space aggregation of all factors, value chains, and industry chains in virtual worlds. It also incorporates new social models and economic models. Through means such as human–machine interaction and digital identities, it collaboratively carries out industrial production and business activities to promote industrial transformation-upgrading and innovative development.

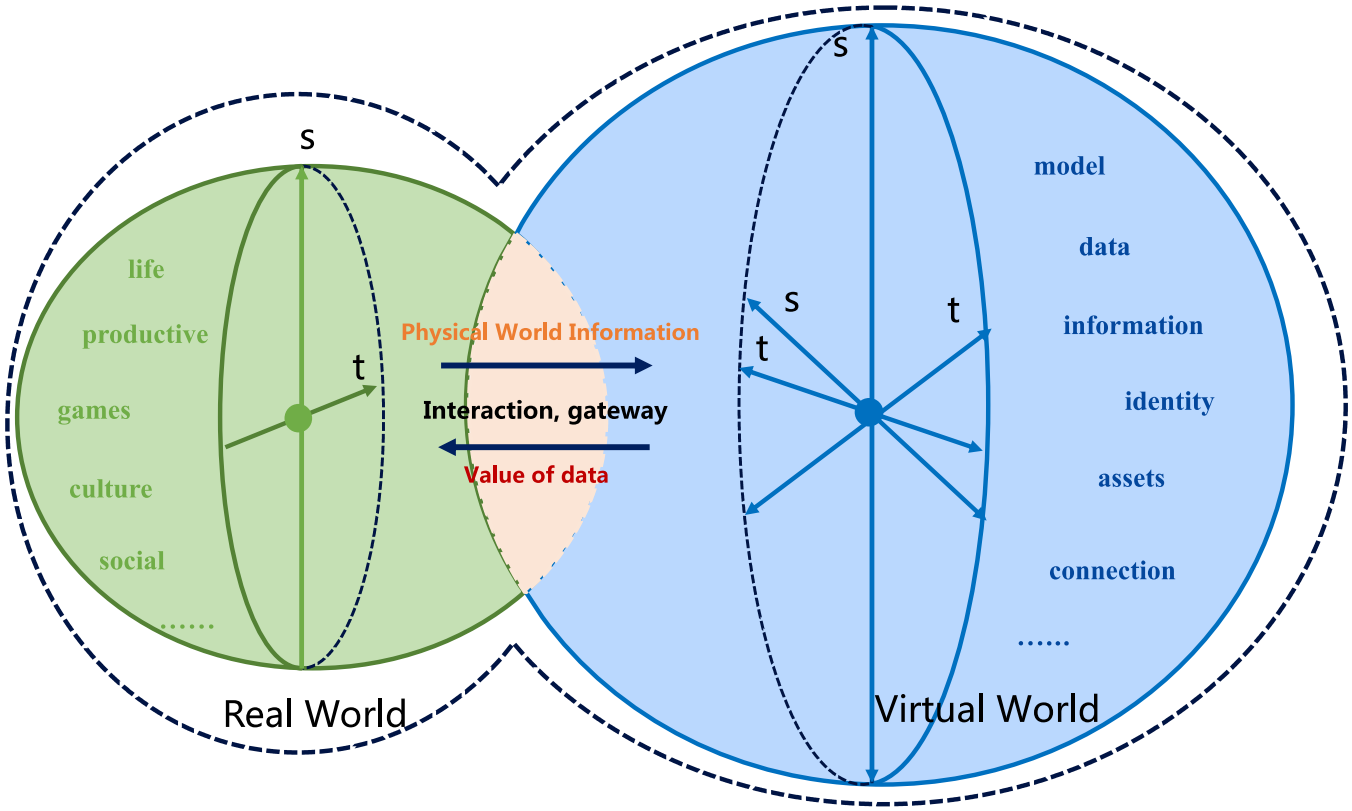
The concept of the Industrial Metaverse is relatively cutting-edge, involving complex technologies and diverse industry types. The industrial ecosystem of the Metaverse has not yet been fully established and perfected, but the exploration of applications related to the Industrial Metaverse is gradually unfolding. In order to build consensus and guide the industry to explore the Industrial Metaverse collaboratively, this report is specially prepared to elaborate on the concept, potential changes, conceptual framework, and supporting system of the Industrial Metaverse. It also provides recommendations for promotion, aiming to provide reference and guidance for the practical application and industrial development of the Industrial Metaverse.

1. OVERVIEW

1.1. CONNOTATION OF METAVERSE

The Metaverse currently lacks a unified definition. The Metaverse refers to a virtual world created using technological means that interacts with the real world, forming a digital living space with a new social and economic system. Based on various definitions of the Metaverse, it can be seen as an immersive, autonomous, and integrated digital network space that combines multiple information technologies organically. It is a virtual economic system based on the reconstruction of value on internet platforms, assetization of identity, valorization of content, and open interoperability. It is also a new type of network society that extends the depth of real-world social activities and interpersonal relationships in time and space. The Metaverse utilizes technologies such as augmented reality (AR), blockchain, artificial intelligence (AI), and digital twins to achieve digital expansion of the real world by extending its spatial dimensionality, temporal dimensionality, and value extension.

FIGURE 1 **Metaverse schematic diagram**



1.1.1. MAIN CHARACTERISTICS OF THE METAVERSE

The main feature of the Metaverse is to help people achieve their digital avatars in the virtual world and then integrate the virtual world with the real world through means such as AR. From the perspective of Metaverse digital avatars, the Metaverse mainly has four main characteristics: spatiotemporal integration, pluralistic coexistence, value interoperability, and autonomous diversity. Spatiotemporal integration refers to expanding the real world digitally and providing various possibilities for development in time and space. With the help of the Metaverse, users can develop multiple timelines and experience life in different spaces and scenarios, greatly increasing future possibilities. Pluralistic coexistence means the Metaverse can unify multiple identities and bind virtual identities with real ones. Avatar will become a major characteristic of Metaverse identity. Value interoperability means that the Metaverse realizes value circulation and integration between the real world and the digital world. A new economic system will emerge where important data from the real world will transform into significant digital assets, and digitized creations in virtual worlds may also turn into tangible wealth. Autonomous diversity means that the Metaverse gives users full autonomy and freedom; they can freely control how their personal identity information is applied and choose which scenes they want to be immersed in.

1.1.2. METAVERSE DEVELOPMENT TRENDS

The development trend of the Metaverse can be described from four aspects: integration of virtual and real, ecological connectivity, human–computer interaction, and information interaction.

First, the integration of virtual and real will continue to strengthen. The Metaverse is the combination of the physical and digital worlds. From the perspective of world integration, the Metaverse may go through three stages: independent development, integration of virtual and real worlds, and symbiosis of virtual and real. In the stage of independent development, the digital world is subordinate to the physical world, and there is not much interaction between the two. In the stage of integration of virtual and real, the physical world and the digital world interact frequently, and they influence each other. In the stage of symbiosis of virtual and real, the digital world is highly integrated with the physical world, and it approaches or even surpasses the physical world in terms of time, space, economy, and other dimensions, leading to new social forms.

Second, the scope of applications will continue to expand. From the perspective of application development, the Metaverse will go through the stages of spontaneous development, interconnection of domains, and full connectivity. In the initial stage, some independent applications appear sporadically, and then, the applications

begin to aggregate based on domains and application goals, forming domain ecosystems and finally achieving comprehensive interconnection to form a Metaverse application ecosystem.

Third, the user experience of human–computer interaction will continue to improve. From the development of interaction technologies, the Metaverse will promote the transformation of traditional interactions, such as text and video, toward audiovisual immersive interactions based on AR. Ultimately, it may encompass and even surpass the full-sensory immersive interaction of the human body, achieving a truly meaningful Metaverse interaction mode.

Fourth, the mode of information interaction will shift toward decentralization. From the perspective of information interaction concepts, the Metaverse will drive the evolution of the internet from a network–person interaction and person–person interaction based on information reading toward a Web3.0 dominated by intelligent person–network interaction.

1.2. CONNOTATION OF INDUSTRIAL METAVERSE

The Industrial Metaverse is an important application field of the Metaverse, which is a new industrial ecosystem that deeply integrates next-generation information and communication technologies such as AR, digital twins, and content generation with the physical industrial economy.

Compared with the creation of surreal content and user experience in consumer scenarios, the scenes and objects constructed in the Industrial Metaverse are a concrete physical system with clear problems to be solved, organizational relationships, and tasks. Thanks to the solid technological foundation and clear industrial scenarios in the industry field, the future Industrial Metaverse may be the direction for the prioritized implementation of Metaverse applications.

2. POTENTIAL CHANGES

2.1. PLATFORM-BASED DESIGN OF TIME AND SPACE INTEGRATION

The Industrial Metaverse can simulate product design, production, and usage environment to provide a more intuitive and accurate simulation and display of the interaction between products and their components. During the design and development phase, product designers can break through collaboration boundaries in time and space by using the virtual–physical fusion environment created by the Industrial Metaverse, greatly enhancing the collaboration experience and efficiency. Designers can also use VR (Virtual Reality) or AR (Augmented Reality) glasses to immerse themselves in the design effects and complete various human–machine engineering designs and optimizations through "real" management experiments.

2.2. INTELLIGENT MANUFACTURING WITH THE COMBINATION OF VIRTUAL AND REAL

The Industrial Metaverse will be able to replicate and aggregate real-world production resources in the virtual world, enhancing global production collaboration capabilities, and constructing a global "mega-production line" model. In the Industrial Metaverse, the boundaries of time and space become blurred. Enhancing operators' real-time perception of the operating environment is possible by constructing a remote operation mode that provides a sense of being on-site. This can avoid personal safety issues caused by on-site production scenes. It can also achieve multiuser immersive remote production monitoring, operation guidance, etc.

2.3. PERSONALIZED CUSTOMIZATION FOR IMMERSIVE EXPERIENCES

The Industrial Metaverse can build an open, transparent, and intuitive product life cycle scenario view in the virtual world, attracting more people to participate in product production in various forms. Users can participate in product design, observe, and even participate in the product production process in the virtual world built by the Industrial Metaverse, conduct product virtual experiences, and provide feedback suggestions on product improvement or optimization at any time. They can also directly consume products after the above process, track the product logistics process, and give feedback on product use.

2.4. GLOBALLY VISIBLE NETWORKED COLLABORATION

The Industrial Metaverse can further deepen the transformation of organizational models in the industrial chain and supply chain. Enterprises and partners on the industrial and supply chains can collaborate in virtual worlds for collaborative design, production, and services. Collaborative experiences are more intuitive and efficient, and through the integration of virtuality and reality, 3-D displays, immersive experiences, and precise display of complete collaboration processes and views can be achieved. This promotes resource sharing, capability transactions, and business optimization configuration.

2.5. SYMBIOTIC EXTENSION OF SERVITIZATION

The Industrial Metaverse can support enterprises in creating various virtual images and scenes, breaking the boundaries of time and space to communicate with users more efficiently, and obtaining more accurate information about user product usage through technologies such as mapping and embodiment of the real world. Through VR and AR devices, customers of enterprise products can see real-time product operation processes and usage requirements, effectively reducing training difficulty and minimizing operational errors. Equipment suppliers for enterprises can enter virtual factories through AR and VR to obtain more precise situational information, accelerating fault localization, cause investigation, and fault repair.

2.6. DIGITAL MANAGEMENT OF HOLOGRAPHIC INSIGHTS

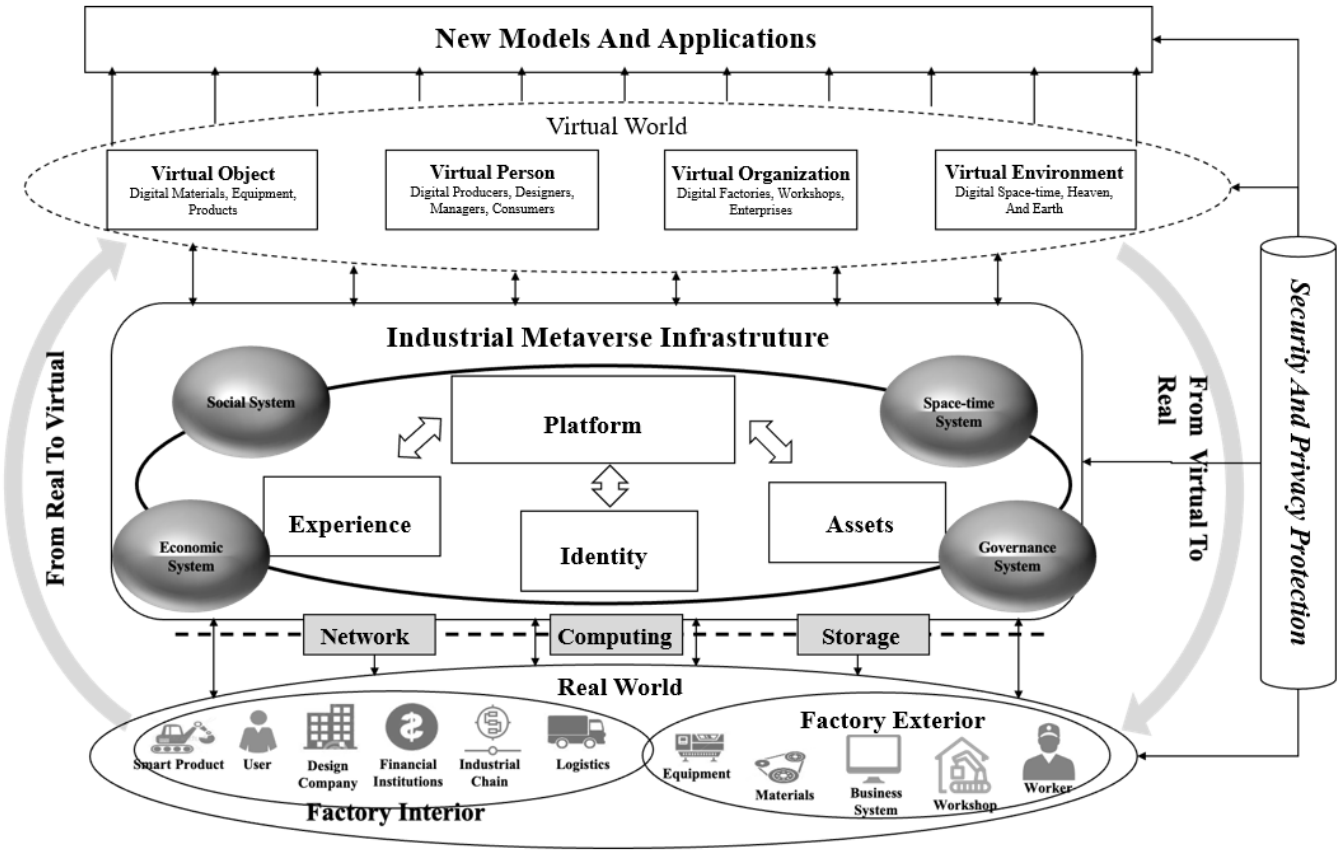
The Industrial Metaverse can showcase in real time the construction, operation management, production equipment, and production line status of smart factories in the virtual world. It provides a more intuitive and convenient way to optimize, innovate, and even reshape enterprise-related activities. In the early stage of smart factory construction, a virtual smart factory that is consistent with the architectural structure, production line layout, production process, and equipment structure of the actual smart factory is built to verify the rationality of capacity allocation, equipment structure, and personnel flow in advance. During the operation phase of smart factories, comprehensive 3-D visualization display, simulation, and predictive analysis can be conducted in the virtual smart factory for all scenarios, processes, and elements.

3. CONCEPTUAL FRAMEWORK AND DEVELOPMENT STAGES

3.1. CONCEPTUAL FRAMEWORK

As an important application scenario of the Metaverse, the Industrial Metaverse mainly aims to achieve the mapping from the industrial real world to the virtual world and realize new developments in industrial production in the virtual world.

FIGURE 2 **Framework of the Industrial Metaverse**



Real World: In addition to industrial production, the real world also includes a comprehensive perception of all elements, the entire industry chain, and the entire value chain. All elements include people, machines, materials, methods, environment, and quality. The entire industry chain consists of multiple links, such as procurement, production, logistics, and sales, forming a complete industrial chain. The entire value chain includes the organization of all participants and activities, such as production and sales, and the distribution of value and

profits. The real world has built a solid data foundation for the Industrial Metaverse through the digitization of all elements, the entire industry chain, and the entire value chain.

Infrastructure: With the support of key information infrastructure such as networks, computing power, and storage, the Industrial Metaverse further builds infrastructure with Industrial Metaverse characteristics, including experience, identity, assets, and platforms, forming four major systems: social, temporal, economic, and governance. Among them, the experience infrastructure mainly focuses on the development of virtual and real interaction and content and rendering engines. The identity infrastructure mainly represents and associates virtual and real identities, supporting the realization of “avatars” in the Industrial Metaverse and serving as an important foundation for internal social relationships. The platform infrastructure supports the collaborative coordination of virtual and real resources in the Industrial Metaverse, provides data-driven industrial intelligence and services for the entire system, supports the interaction between experience, identity, and assets, and supports the construction of a new social, economic, temporal, and governance system for industrial production and management. It also supports the construction of virtual worlds and various innovative applications in the Industrial Metaverse.

Virtual World: Based on the mirror image of the real world, supported by the infrastructure of the Industrial Metaverse, and within the social, temporal, economic, and governance systems, the virtual world consists of digital elements such as virtual objects, virtual individuals, virtual organizations, and virtual environments. Virtual objects mainly represent the production materials of the real world, including digitized materials, equipment, and products. Virtual individuals mainly represent the participants in industrial production, including digitized producers, designers, managers, and consumers. Virtual organizations mainly represent production entities, including digitized factories, workshops, enterprises, and industrial parks. Virtual environments mainly represent production environments, including digitized time, space, and buildings. In the future, the virtual world will become an important carrier for industrial production and management in the era of the Industrial Metaverse.

Emerging Models and Applications: Leveraging the integration of virtual and real, the Industrial Metaverse greatly expands the real world of industrial production, eliminates temporal and spatial limitations, and integrates and schedules physical and digital resources on a larger scale. With the interactive means, presentation methods, collaborative models, and transformations of social, economic, and governance systems brought by the Industrial Metaverse, further innovative development is achieved in six typical application models: platform-based design, intelligent manufacturing, personalized customization, networked

collaboration, service extension, and digital management. This leads to comprehensive design, production, manufacturing, service, and management improvements.

Based on these foundations, participants such as users, content creators, operators, platform builders, infrastructure providers, and platform regulators, as well as focusing on the commonality of the Industrial Metaverse infrastructure and sectors such as manufacturing, energy, healthcare, and transportation, engage in innovative exploration, and promote the construction and development of a new industrialization system.

3.2. DEVELOPMENT STAGES

As an important application scenario of the Metaverse, the development of the Industrial Metaverse follows the general laws of Metaverse development. It has similar development trends in terms of virtual and real integration, ecological connectivity, human–machine interaction, and information interaction. However, due to the complexity of industrial applications and their coupling with production, the development of the Industrial Metaverse also has its own characteristics.

In the initial stage of development, the existing production processes and demand structures of the real world have not changed significantly. The construction of virtual elements such as virtual objects, virtual people, virtual organizations, and virtual environments must gradually align with practical needs and scenarios. The degree, depth, and breadth of integration between the real and virtual worlds are still in the early stages, constrained by the development of supporting systems for the Industrial Metaverse, the development of socio-economic governance systems, and the complexity of industrial scenarios. During this stage, the Industrial Metaverse focuses on “point” explorations.

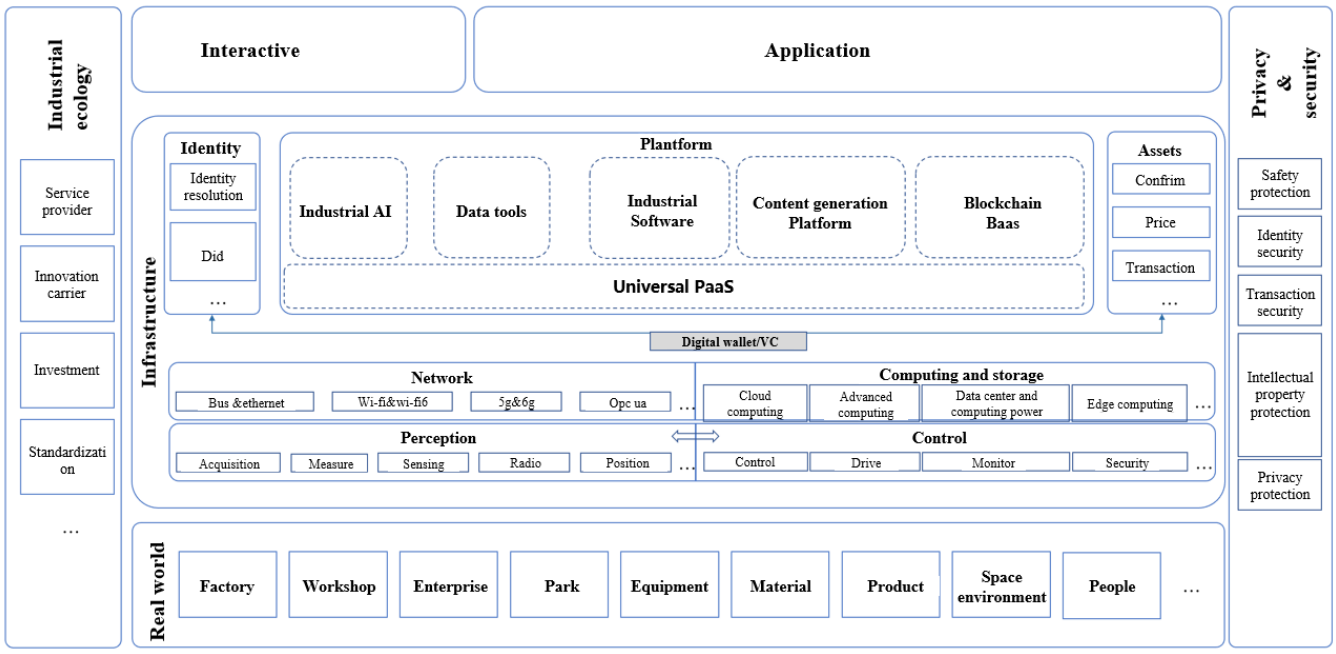
In the rapid development stage, the virtual world becomes more realistic and actively participates in transforming the production processes of the real world. The supporting systems for the Industrial Metaverse, including technologies, interactive devices, and infrastructure, are relatively mature. Activities such as design, production, manufacturing, services, and management accelerate their mapping or migration to the virtual world. Numerous innovative application models that are replicable and scalable emerge, leading to innovations in social and economic activities and driving changes in governance systems.

In the mature development stage, the Industrial Metaverse combines virtual and real aspects of industrial production. There is complete mapping and seamless interaction between the virtual and real worlds, allowing people to participate in various production and operation stages by integrating virtual and real elements.

4. TECHNOLOGY ARCHITECTURE

The development of the Industrial Metaverse needs to build a strong support system involving new infrastructure construction, technological product innovation, industrial ecological cultivation, and the establishment of supporting policies and regulations to support the development of the Industrial Metaverse.

FIGURE 3 Support system of the Industrial Metaverse



4.1. PERCEPTION AND CONTROL

Perception is an important data source and data basis for the operation of the Industrial Metaverse. Through audio and video collection, measurement, sensing, radio frequency identification, location information collection, and other data collection means, the all-around perception of industrial production and operation activities can be achieved. Control applies industrial information and control systems and information and instructions from the virtual world to the real world, changing the operational status of real-world assets and enabling users to control production and business activities under the virtual interaction interface.

4.2. NETWORK, COMPUTING, AND STORAGE

The explosive growth of data volume brought about by the Industrial Metaverse, the demand for holographic communication, virtual reality interaction, digital asset transaction, decentralized interaction, and the shaping of the social system, economic system, time–space system, and governance system supporting the development of the Industrial Metaverse all put forward leapfrog development requirements for the existing information infrastructure, network bandwidth, and transmission delay. The continuous increase in demand for computing power and other aspects has also brought huge challenges to the construction of communication technology and infrastructure. Among communication technologies, network technologies such as industrial Ethernet, 5G/6G, and Wi-Fi 6 provide more reliable, fast, and flexible data transmission capabilities, and need to adapt to the development of Industrial Metaverse applications. For example, high real-time applications in the virtual reality fusion scenario require network millisecond delay. Computing technologies, such as edge computing, cloud computing, and computing power centers, provide distributed and low-cost data computing capabilities for different industrial scenarios, especially distributed technology applications, such as blockchain, digital avatars, digital asset transactions, etc., which will bring great challenges to network computing capabilities and storage capabilities.

4.3. PLATFORM

The platform provides general capability support for constructing and operating the Industrial Metaverse. It provides massive data analysis, spatial–temporal modeling, content creation, resource collaboration, asset trading, industrial control, application development, and other functions through the aggregation of virtual and real data, virtual and real assets, virtual and real resources, model tools, digital identity, spatiotemporal status, and other information. It is the core of the Industrial Metaverse.

- Industrial Artificial Intelligence

  Industrial AI is the key to building and driving industrial virtual worlds and achieving virtual real linkage. The creation of a virtual world needs AI. In the Industrial Metaverse, users have broken through the time and space constraints to communicate; however, the construction of virtual scenes requires a lot of effort. It needs AI technology to build an intelligent “brain” to innovate content and reduce the threshold of user content creation. The “digital person” in the virtual world needs AI. The avatar is the main function of the Industrial Metaverse to provide users. In addition to the digital identity corresponding to reality, digital avatars also have some “digital people” dedicated to serving virtual scenes. These roles

need AI technology to endow certain intelligence to complete corresponding responsibilities. The automatic management of the Industrial Metaverse needs AI. Autonomy is the key capability of the Industrial Metaverse. When responding to various emergencies, the Industrial Metaverse can automatically adjust, optimize its behaviors, and ensure its operation. Industrial AI will continue to develop in areas such as generation algorithms, multimodality, content generation, and pretrained models in the future.

- Industrial Data Management and Tools

  Industrial data management and tools provide important support for the Industrial Metaverse to realize massive data analysis, management, governance, and intelligent decision-making based on this. Through the convergence of industrial production, operation, management, and other data in the real world and virtual world, with the help of industrial models and data science such as data modeling, data identification, and data governance, combined with industrial AI technology, the Industrial Metaverse data system is built to promote the intellectualization and capitalization of industrial data, and form deeper and more accurate data insight, analysis and prediction, decision feedback, and visual display. It also acts on industrial activities in the real world and virtual world, providing a basis for the automatic and intelligent operation of the Industrial Metaverse.

- Industrial Software

  Industrial software provides tool components for the Industrial Metaverse, such as CAD (Computer Aided Design), MES (Manufacturing Execution System), ERP (Enterprise Resource Planning), etc., uses core technologies such as process optimization and simulation verification to manifest industrial knowledge further, and supports advanced applications such as virtual modeling and simulation of factories and production lines, and dynamic scheduling of multivariety and variable batch tasks. In the future, it needs to be combined with the 3-D presentation, digital twin, virtual reality interaction, and other technologies to support various production, operation, and management activities of virtual reality combination/virtual reality integration in the Industrial Metaverse.

- Content Generation Platform

  The content generation platform provides text, picture, audio and video, and other content generation services for the Industrial Metaverse to build a digital image of the real world, create a virtual world, build a digital avatar or digital person, and virtual reality interaction, including time–space engines,

content engines, real-time rendering, and other tools. AI-generated content (AIGC) is becoming an important solution for content generation in the Metaverse. In the Industrial Metaverse, the content generation platform needs to relate to the demand of industrial activities to accelerate the implementation of industries.

- Blockchain BaaS Platform

  Blockchain technology can endow data with the characteristics of being difficult to tamper with, thus supporting the cross-platform management and circulation of data/resources/assets. Users really own digital assets, which is the foundation for the Industrial Metaverse to build a credible value network and a new economic system. The blockchain BaaS platform can provide services such as smart contracts, consensus algorithms, privacy computing, cross-chain mechanisms, etc., promote the application of blockchain in the Industrial Metaverse, promote the flow, collaboration, and sharing of various virtual and real data/resources/assets among different manufacturing entities, and accelerate the reconstruction of existing business logic and business models.

- Universal PaaS Platform

  The general PaaS platform provides the Industrial Metaverse platform with basic common support such as system resource scheduling and operation and maintenance management through cloud computing, big data, and other technologies.

4.4. DIGITAL IDENTITY AND ASSETS

The Industrial Metaverse will be a world of lasting operation and integration of reality and fiction, and its value is an important basis for its existence. The confirmation, pricing, and trading of assets are the fundamental guarantees for stimulating data elements, digital native innovation, and the circulation of virtual and real resources/assets to achieve economic benefits, especially for industrial production and operation activities. The confirmation, pricing, and trading of assets require policy guarantees and industry self-discipline and rely on information technology tools and mechanisms such as blockchain. It is necessary to consider both the value extension of the virtual world to the real world and the connection with the economic system of the real world.

Digital identity is the unique representation of people/machines/objects in the real world and in the virtual world in the Industrial Metaverse. It involves the unique identity, associated information, identity verification, associated information search, and positioning of digital identity. The industrial internet identity resolution

system and the new identity system represented by distributed identity will provide important basic support. At the same time, digital wallet technology can also be used to realize the binding of digital identity and digital assets, as well as digital asset transactions on this basis. By utilizing technologies such as digital avatars, enterprises can be supported to create various virtual images and scenes while also attracting people to break the boundaries of time and space and participate in industrial production and operation activities with the help of digital avatars.

4.5. INTERACTIVE MODE

The Industrial Metaverse will bring a new human–computer interaction mode and experience. With the help of natural language, extended reality, brain–computer interface, digital agents, and other interactive technologies and devices, the combination of virtual reality or virtual reality integration can be achieved, and the required interaction environment can be customized and developed according to the industrial scene to make the interaction experience more real and smooth. With the development of the Industrial Metaverse, higher requirements are constantly put forward for the technical capabilities of interactive devices in optics, chips, sensing, and perceptual interaction, including stability, accuracy, real-time, user-friendliness, and lower cost. The forms of interaction, such as Brain–computer interface, are constantly innovating and developing, and the scope of interaction is also developing from the traditional human interaction to the hybrid interaction between human and digital agents.

In terms of application, the Industrial Metaverse will enable thousands of industries and promote the innovative development of design, production, manufacturing, service, and management through the combination of virtual reality/integration of virtual reality.

5. SUMMARY

The Industrial Metaverse aims to create a virtual world that maps and interacts with the real industrial economy, constructing an intelligent and efficient collaborative closed-loop environment centered around products, enterprises themselves, upstream and downstream enterprises, consumers, and even the entire industrial ecosystem. This will promote the development of the industry toward a higher stage of holographic intelligent production and management. Currently, the Industrial Metaverse is still in its early stages of development. There are still many limitations in terms of network transmission capabilities, content engine development, application scenario innovation, virtual-to-real mapping, and interaction. The real-time nature, interactivity, immersion experience, and realism of Industrial Metaverse applications still need to be improved. In particular, relatively few core business processes and application systems focus on manufacturing process twinning. There is still a significant gap between the implementation of Industrial Metaverse applications; however, digital twinning in factories has shown effectiveness along with immersive product experiences and AR/VR training applications. In the future, as exploration continues and technological innovations unfold, the Industrial Metaverse will gradually mature.

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