The Industrial Metaverse is an accelerator for new-type industrialization in the Guangdong-Hong Kong-Macao Greater Bay Area.

Authors: Xiaodong Zhou, Zhou Xiaodong

Date: 2025-10-25T00:00:00+00:00

Abstract

This study investigates the fundamental concepts of the metaverse and industrial metaverse, along with the characteristics of their primary related technologies, indicating that the industrial metaverse represents a novel stage in the digitalization and intelligentization development of industry and the broader industrial sector. It introduces how various districts of Guangzhou vigorously support metaverse empowerment of traditional industries from a strategic perspective, with each district emphasizing different aspects of metaverse industry development. Guangzhou possesses inherent advantages in hardware and software for metaverse industry development, hosts multiple advantageous industries for metaverse scenario applications, and the integration of digital and real economies establishes a robust foundation for Guangzhou' s metaverse industry development. The paper expounds that the industrial metaverse constitutes a new spacetime for the integrated development of Guangzhou' s digital and real economies, serves as a catalyst for developing new quality productive forces in the Greater Bay Area, and represents a significant driving force for new industrialization. Addressing deficiencies and imbalances across Guangzhou' s regions in advancing the industrial metaverse, the study proposes recommendations including: refining top-level design, strengthening overall coordination, constructing comprehensive scenario demonstrations, building a collaborative agglomeration ecosystem, establishing a technological breakthrough system, promoting integration and sharing of regional innovation elements, and developing a regional manufacturing innovation coordination mechanism.

Full Text

The Industrial Metaverse as an Accelerator for New Industrialization in the Guangdong-Hong Kong-Macao Greater Bay Area

Zhou Xiaodong (School of Accounting, Guangdong Technology College, Zhaoqing, Guangdong 526100)

Abstract

This paper examines the fundamental concepts of the metaverse and industrial metaverse, along with the characteristics of their key enabling technologies, arguing that the industrial metaverse represents a new stage in industrial and industrial digitalization and intelligent development. The study introduces how various districts in Guangzhou strongly support metaverse empowerment of traditional industries from a strategic perspective, with each district emphasizing different aspects of metaverse industry development. Guangzhou possesses advantages in both hardware and software for metaverse industry development and boasts multiple advantageous industries for metaverse scenario applications, creating a solid foundation through deep integration of digital and physical economies. The paper elaborates that the industrial metaverse constitutes a new spatiotemporal dimension for the integrated development of Guangzhou' s digital and real economies, serves as a booster for developing new quality productive forces in the Greater Bay Area, and represents a crucial driving force for new industrialization. Addressing shortcomings and imbalances in advancing the industrial metaverse across different Guangzhou districts, the paper proposes recommendations including improving top-level design, strengthening overall coordination, constructing comprehensive scenario demonstrations, building collaborative agglomeration ecosystems, establishing technology research systems, promoting integration and sharing of regional innovation elements, and developing collaborative innovation mechanisms for regional manufacturing.

Keywords: Metaverse, VR/AR, Artificial Intelligence, Industrial Metaverse, Digital Twin

The metaverse is a collection of virtual spatiotemporal realms, a digital world that links, integrates, and creates through modern technological means, mapping and interacting with the real world. It constitutes a digital manufacturing, service, work, and living space with modern and future social systems—a parallel universe running alongside human society in digital form. Through augmented reality (AR), virtual reality (VR), mixed reality (MR), extended reality (XR), and Internet technologies, the metaverse delivers immersive experiences.

The industrial metaverse represents the deep integration of digital technology and manufacturing, serving as a critical driver for future manufacturing transformation. It is an industrial ecosystem where new information and communication technologies such as extended reality (XR) and digital twins deeply

merge with the physical industrial economy. Through XR, artificial intelligence (AI), Internet of Things (IoT), cloud computing, blockchain, and digital twin technologies, it enables seamless connections among people, machines, materials, and systems, integrating modern digital technology with real-world industry to promote sustained and efficient development of physical industry. It constructs a new manufacturing and service system covering the entire industrial chain and value chain, marking a new stage of industrial digitalization and intelligent development.

1. The Industrial Metaverse Boosts New Quality Productive Forces Development in the Greater Bay Area

In July 2024, the Decision of the Central Committee of the Communist Party of China on Further Deepening Reform Comprehensively to Advance Chinese Modernization, adopted at the Third Plenary Session of the 20th CPC Central Committee, called for "improving the institutional mechanisms for developing new quality productive forces according to local conditions" and "perfecting the system for promoting the deep integration of the digital and real economies" (China Government Network, 2024). New quality productive forces, driven by innovation, break away from traditional economic growth models and productivity development paths. They represent an advanced productive force characterized by high technology, high efficiency, and high quality, aligning with new development concepts. As a concrete manifestation of advanced productive forces, new quality productive forces constitute a Chinese innovation and practice of Marxist productivity theory, representing fundamental outcomes generated by breakthroughs in integrated scientific and technological innovation. The industrial metaverse integrates modern digital technology with real-world industry, powerfully promoting sustained and efficient development of physical industry in the Greater Bay Area, and building a new manufacturing and service system covering the entire industrial chain and value chain, thereby boosting new quality productive forces development in the Greater Bay Area.

1.1 The Metaverse as a New Internet Application and Social Form Integrating Virtual and Real

The metaverse is a parallel universe that exists in digital form alongside human society, created through modern technological means for linking, integration, and creation. It is a digital world that maps and interacts with the real world, constituting a digital manufacturing, service, work, and living space equipped with modern and future social systems. As a new internet application and social form integrating multiple technologies, the metaverse leverages AR, VR, MR, and internet technologies to deliver immersive experiences, earning it the designation of Web 3.0. It can be further subdivided into spatial internet and value internet. The metaverse will empower all industries, including manufacturing, stimulating new functions for innovation and development in traditional sectors and enabling industrial transformation and high-quality development.

1.2 The Industrial Metaverse as a Key Driver of New Industrialization

The industrial metaverse fully utilizes data from physical models, sensor updates, and operational histories, combining XR technology to simulate digital employees, multi-physical quantities, multi-dimensions, multi-probabilities, and real-time industrial simulation processes. It maps the real physical world into virtual space, which can be a new application model for digital technology mapping of one or multiple important, interdependent real equipment systems, thereby optimizing physical equipment and processes in industrial manufacturing. The industrial metaverse creates 落地空间 for personalized customization, mass customization, flexible manufacturing, and product lifecycle operation and maintenance services. Industrial metaverse based on "dark factories"(a new type of intelligent unmanned factory), digital twins, CPS (Cyber-Physical Systems), AR, and VR will overturn current economic and social structures, allowing different traditional industries to be reborn in the industrial metaverse.

In early September 2023, five ministries and commissions including China' s Ministry of Industry and Information Technology, Ministry of Education, Ministry of Culture and Tourism, State-owned Assets Supervision and Administration Commission of the State Council, and National Radio and Television Administration jointly issued the Three-Year Action Plan for Metaverse Industry Innovation and Development (2023-2025) (MIIT Joint Science [2023] No. 49). With building the industrial metaverse and empowering manufacturing as primary goals, and driven by the integration and innovation of new-generation information technologies, the plan proposes 14 key tasks across five areas: constructing advanced metaverse technology and industrial systems, cultivating three-dimensional interactive industrial metaverses, creating immersive digital life applications, building comprehensive industrial support systems, and establishing secure and trustworthy industrial governance systems.

The industrial metaverse represents the mutual integration of industrial physical reality, virtual reality, and augmented reality. It primarily encompasses three layers: First, the industrial material layer, referring to physical assets such as factories, machinery, raw materials, and energy that industrial metaverse development cannot do without, being highly related to concrete industrial production. Second, the industrial technology layer, where the industrial metaverse continuously meets consumers' physical and psychological needs through technological R&D and product/service creation based on existing industrial materials, mainly comprising composite technology layers formed by VR/AR/MR and other extended reality technologies and digital twin technologies, characterized by immersion and interactivity. Third, the industrial interaction layer, where a continuously maturing interaction layer forms under the support of the industrial material and technology layers, enabling enterprise R&D, production, management, and service personnel to simultaneously complete a series of social production and service activities in both physical and virtual worlds, with producers and consumers communicating, interacting, and co-creating value across both realms.

1.4 System Composition, Main Objectives, and Application Scenarios of the Industrial Metaverse

(1) System Composition of the Industrial Metaverse

The industrial metaverse is primarily composed of five systems: technology system, standard system, product system, service system, and guarantee system. The technology system of the industrial metaverse is still evolving and developing. "Currently, it mainly consists of spatiotemporal engines + real-time rendering + large-scale modeling technologies, natural interaction technologies, blockchain technologies, network communication and computing power technologies, artificial intelligence technologies, IoT/sensing technologies, and digital twin technologies. Among them, hot technologies in the industrial metaverse include 5G, computing power networks, virtual reality/augmented reality technologies, digital twin technologies, artificial intelligence technologies, blockchain technologies, industrial metaverse platforms, and advanced computing."[1] From the perspective of the entire product lifecycle, the industrial metaverse has achieved varying degrees of application in industrial R&D, production, management, sales, and training stages. From the industrial system hierarchy, it has realized equipment-level, production-line-level, factory-level, and industrial-chain-level applications, significantly promoting enterprise quality improvement, cost reduction, and efficiency enhancement, as well as serving industrial chain governance and supply chain optimization.

(2) Main Objectives of Industrial Metaverse Applications:

Strengthen Technology Reserves

Focus on the integrated application of new-generation information technologies to systematically review the current status of the industrial metaverse industrial chain in hardware facilities, basic software, virtual platforms, content production, and industry applications. Study the long-term development of industrial metaverse scientific and technological innovation, identify shortcomings in key breakthroughs and integrated applications, expand existing strengths, formulate and deploy strategic plans for metaverse-related technology research, and implement key projects step by step in a targeted manner.

Accelerate Standard Development

"Relying on existing standardization organizations for blockchain, artificial intelligence, AR/VR, brain-computer interfaces, and graphics and images, coordinate domestic standardization efforts to accelerate research on industrial metaverse standardization roadmaps and standard system construction. Focus on standardization needs such as industrial metaverse technical architecture, system integration, and interoperable data asset exchange, and develop key standards in basic, technical, and application categories." [2] Simultaneously, track foreign metaverse standard developments in real-time and ensure good communication and alignment with international standards.

Cultivate Application Scenarios

Focus on channels such as R&D design, production assembly, remote collaboration, sales, and training in industry, as well as subdivided fields like industrial culture digital collections and digital humans, to drive industrial metaverse innovation. Relying on manufacturing transformation and digital China construction, promote large-scale application of the industrial metaverse in industrial manufacturing, metallurgy, agriculture and forestry, ports, mining, aerospace, energy, transportation, and underwater engineering to enhance deep application levels. Drive industrial metaverse development through scenario application pull to achieve digital transformation and quality improvement, cost reduction, and efficiency enhancement, promoting the realization of China' s manufacturing powerhouse and intelligent manufacturing goals.

Build Industrial Ecology

Construct an open, competitive, green, innovative, and sustainable industrial metaverse ecosystem, strengthen industrial metaverse system operation service industries, and significantly enhance industrial chain supply chain resilience. Establish industrial metaverse empowerment innovation centers in key industrial cities, forming a number of influential and distinctive industrial metaverse industry clusters.

(3) Numerous Scenarios of Industrial Metaverse Applications in Manufacturing Processes

Traditional industrial manufacturing processes include design, production, sales, and application. In the metaverse era, marketing becomes more important, making personalized production and order-based production account for an increasing proportion. Internet-based collaborative manufacturing, regional collaborative manufacturing, remote manufacturing, transnational manufacturing, and cloud manufacturing will become trends. In the metaverse era, information about industrial products will undergo tremendous changes—from informatization to digitalization, meaning information becomes more precise, shifting from qualitative to quantitative. Information integrity, timeliness, and real-time capabilities will be substantially improved. Enhanced network capabilities enable stronger communication scenarios and better communication models between producers and customers/consumers, achieving better communication results. Previously transmitted 2D drawings may become 3D models in the future, conveying product motion models to express functions or simulation models to express stiffness and strength. During manufacturing, customers can grasp production progress in real-time; producers can promptly address issues to avoid larger-scale losses; and new ideas can be communicated and implemented in a timely manner. In product application stages, internet, IoT, and mobile network technologies can enable the transition from digital twins to cyber-physical systems, enabling real-time, low-latency remote simulation, control, and maintenance.

New Marketing Models

When customers purchase products, their core need is to satisfy certain requirements. However, customer needs are often uncertain, requiring communication

between supply and demand parties. Communication content includes not only product information but also production capacity, management levels, prices, and costs. "For example, when CSR Ziyang Locomotive Company participated in a U.S. project bid, it modeled based on product drawings provided by the American side, conducted simulation analysis using finite element software, re-optimized product design, and finally won the order." [3] In the metaverse era, communication with customers, production process control, and industrial product application services increasingly need to shift online. Therefore, industrial enterprises must actively consider using virtualization technology to better showcase products, production capabilities, and assurance capacities to meet customer needs and win development opportunities.

Design Model Innovation

Industrial products are often relatively complex, involving multiple fields, making product design a complex process that can be called an open complex giant system. This is typical for personalized products and customer-customized products—not all components need customization but must follow a process of external diversity and internal standardization, comprehensively considering product delivery time, quality, cost, and service convenience.

Industrial product design is also a process. In the metaverse era, greater emphasis is placed on individual creativity, including needs from customers and consumers, as well as ideas from middle and senior management and ordinary employees, gradually transforming from uncertainty to certainty. The virtualization stage includes sketches, 2D drawings, 3D models, analysis models, and machining models. Actual production also often requires a process, with most enterprises having prototype products, preliminary design products, and finalized products. Digital technology requires deepening the application of 3D design, assembly models, industrial styling, simulation analysis, and optimization design software. Physically, it requires utilizing camera arrays, advanced network technology equipment, and large-screen display devices to better showcase, interact, and experience to achieve better product design.

From Intelligent Manufacturing to Smart Manufacturing

Typically, manufacturing processes are material transformation processes, including physical changes like cutting, extrusion, boring, milling, and grinding; chemical changes like pharmaceutical synthesis; and transportation changes involving geographical location shifts. In the information age, these transformation processes also include information changes. Simultaneously, manufacturing processes are human operation processes. Although some work currently has no human involvement, such as fully automated factories, this model applies only to the internal standardized parts of industrial products, not complete products. As complete industrial products require human···

1.5 Digital Twins as the Core Technology of the Industrial Metaverse

Digital twin systems digitally define and model the composition, characteristics, functions, and performance of physical entities based on historical and real-time data, employing new-generation information technologies like artificial intelligence and big data analytics. By constructing an equivalent mapping of physical entities in the information world, digital twins enable simulation analysis and optimization of physical entities, helping users understand and manage the real world more efficiently. In the blueprint of the industrial metaverse, digital twin technology plays a crucial role in manufacturing digital intelligence. Digital twins have eight key technologies that can be fully applied in the industrial field: First, multi-heterogeneous data conversion and integration technology for complex equipment; second, geometric-physical-behavioral-condition modeling technology for complex equipment; third, multi-performance coupling analysis technology for complex state digital twins; fourth, digital twin behavior simulation technology driven by big data; fifth, full lifecycle operation process simulation technology for complex equipment; sixth, intelligent workshop layout planning and production scheduling optimization technology; seventh, operational state visual analysis and fault intelligent prediction technology; and eighth, maintenance operation navigation technology based on augmented reality.[4] "The experiences of the digital self in the metaverse merge with those of the real self in the original reality, with the digital self and real self both relatively distinct as subjects and unified as one subject." The industrial metaverse operates similarly, where digital equipment (or scenarios) and real equipment (or scenarios) are both relatively distinct as subjects and unified as one.

The combination of AI and digital twins makes real-time data analysis possible, enabling predictive maintenance and reducing operational downtime. For example, Shanghai Automotive Gear Factory introduced GE Digital' s Proficy Plant Applications (an industrial informatization solution designed to provide enterprises with capabilities for collecting data from production sites, analyzing information, and building digital twins) to establish process digital twins, increasing equipment utilization by 20% and reducing inspection costs by 40%. Tencent integrates digital twins with AI and cloud computing to help enterprises achieve predictive maintenance and efficient production line management, enhancing production monitoring and simulation capabilities, promoting better decision-making and resource allocation, thereby reducing downtime and operational costs. Baosteel has introduced digital twin technology to construct virtual factories. These digital environments can replicate physical production lines, enabling synchronous transmission of drawings, documents, models, and engineering costs across different workshops. This approach has increased design efficiency by 60% and shortened construction periods by 21%, demonstrating substantial benefits of integrating digital twins into industrial operations. Through virtual factory implementation, Baosteel has achieved data-driven decision-making and quality control throughout the production process, with the integration of virtual and real showcasing the potential of the indus-

trial metaverse in improving manufacturing efficiency and product quality. The foundational technology of digital twins is 3D annotation technology, which uses physical and mathematical models to advance systems engineering. While digital twins previously aimed primarily at optimizing engineering applications, in the future metaverse, digital twin technology can achieve more objectives.

2. Guangzhou' s Practice of Deep Digital-Physical Integration in Developing the Industrial Metaverse

The metaverse is becoming an important track for driving global digital economic development and digital technology innovation. Since 2021, multiple districts in Guangzhou have adapted measures to local conditions and made forward-looking layouts, comprehensively accelerating metaverse industry development and application to facilitate deep integration of digital technology and the real economy, demonstrating characteristics of "good foundation, early start, and initial effectiveness."

2.1 Guangzhou's Industrial Metaverse Has a Solid Development Foundation

(1) Hardware and Software Foundation, Exploring "Ultra-HD + VR Metaverse" Tracks

Guangzhou is home to over 6,932 digital product manufacturing enterprises and 3,796 computer software enterprises, with more than 40 enterprises in semiconductor discrete device manufacturing and wearable smart device manufacturing. The city has 26 cloud computing enterprises in its database, and Huangpu District has gathered over 300 blockchain enterprises, forming an industrial cluster.[5] Nansha District has promoted "certificate-free free trade zone" reforms through blockchain technology, constructing government service infrastructure such as blockchain query and verification service platforms. Tianhe District has also begun building metaverse application scenarios based on blockchain technology, providing a solid foundation for industrial metaverse development.

Guangzhou ranks first in CCID' s "2022 Top Ten New Display Cities," with over 100 major enterprises in the ultra-HD video industry, ranking second nationally in ultra-HD panel production capacity. Guangzhou' s display module market share and 4K board shipments have ranked first globally for consecutive years,[5] achieving multiple national and world-leading innovations in core technology fields, forming a complete ultra-HD industrial chain from display panels, front-end recording, content production, and content broadcasting to terminal products and industry applications. The industry demonstrates distinctive features including large-scale core component manufacturing, broad display technology layout routes, and strong industrial cluster synergistic effects. As a core area of the national ultra-HD video industry development pilot zone, Guangzhou is fully advancing toward building a world display capital and a globally competitive ultra-HD video industry cluster.

Guangzhou has become a national ultra-HD content production and aggregation center, with abundant supply driving a vast new consumer market for terminal manufacturing and application expansion that must rely on innovation. Guangzhou' s commercial 8K broadcast vehicle is equipped with "Starry Sky," China's first 8K+3D VR live broadcast shooting system, which opens broad consumer markets through its professional-grade technology and content creation. "Starry Sky" combines high-resolution 8K, 3D, and VR technologies, enhancing clarity and stereoscopic effects to deliver authentic immersive experiences. This technological breakthrough eliminates spatial constraints, restores scenes, and holds enormous market potential in live streaming, gaming, sports events, and numerous other fields.[6] Guangzhou' s ultra-HD industry enterprises are competitively launching innovative products. Pearl River Digital has opened remote medical systems connecting 21 prefecture-level city health bureaus and 30 designated hospitals; internet backbone enterprises like NetEase and Kugou promote VR/AR industry agglomeration and integrated innovation; Huiyan Technology provides intelligent equipment covering robot assembly, labeling, and code reading applications.[6] Guangzhou is exploring "ultra-HD + VR metaverse" tracks, unlocking potential application scenarios for ultra-HD in cultural and sports activities, remote medical care, and live e-commerce, continuously unlocking new markets.

(2) Guangzhou Focuses on Innovation to Break Through AI Technology Bottlenecks

In April 2023, the Pazhou Algorithm Library officially launched, with the first batch of approximately 100 industrial algorithm models moving in. Guangzhou is building a high-level R&D platform system, creating a "1+6+N" innovation system led by the Guangdong Provincial Laboratory of Artificial Intelligence and Digital Economy, supported by six Guangdong Provincial New Generation Artificial Intelligence Open Innovation Platforms, and participated in by numerous key laboratories, new R&D institutions, and enterprise technology centers to drive continuous breakthroughs in core technologies. "The brain-computer interface technology of the Guangdong Provincial Laboratory of Artificial Intelligence and Digital Economy leads nationally, having developed brain-computer AI smart wards, meditation brain-computer interface interaction systems, and brain-computer fatigue driving warning systems." [7]

Guangzhou cultivates globally leading enterprises. It has established major AI science and technology special projects, focusing on supporting applications and innovation platforms. In the intelligent manufacturing field, Guangzhou pioneered the "Four Modernizations" empowerment special action nationwide, creating four intelligent manufacturing demonstration factories named as 2023 National Intelligent Manufacturing Demonstration Factories: Sinopec Guangzhou Petrochemical Branch, Guangzhou Tech-Long Packaging Machinery Company, Inpai Battery Technology Company, and Guangzhou Guanghe Technology Company. Additionally, 15 enterprises including Guangri Elevator, Guangzhou Shipyard International, and Schneider (Guangzhou) were listed in the "2023

Intelligent Manufacturing Excellent Scenarios List," ranking first in Guangdong Province. The smart medical field already has multiple smart hospitals; the smart city field has built the "Suizhiguan" smart city brain. Empowering industries with rich application scenarios, Guangzhou selected 100 typical cases of AI application scenarios and released the "Top 30 Most Innovative Value Landing Cases" list, fully unleashing the leading demonstration power of leading enterprises.

AI development is gradually showing characteristics of strong application penetration, rapid technological innovation, and intense international competition, accelerating deep integration with industries and demonstrating powerful enabling effects. Guangzhou has made beneficial explorations in AI industry development, building advantageous tracks. In recent years, Guangzhou has adhered to application traction, opening up four advantageous tracks: "vehicle building healthy city" (intelligent manufacturing, intelligent driving, smart healthcare, smart city), cultivating unique AI application scenarios and ecosystems. In April 2023, the Baidu PaddlePaddle (Guangzhou) AI Industry Empowerment Center landed in "Pazhou Algorithm Valley," aiming to empower industries in Guangzhou and even the Greater Bay Area, supporting enterprises and developers to bypass complex underlying technology research and achieve cost-effective industry application implementation. Guangzhou' s electronic information manufacturing industry leads nationally, with advantages including long industrial chains, concentrated innovation elements, and rich application scenarios. "The comprehensive penetration of AI in Guangzhou' s urban transportation and autonomous driving fields has also brought disruptive transformations; the world' s first smart metro demonstration station was built, with L4 autonomous driving and drone technology leading the nation." This represents bold explorations by Guangzhou enterprises such as Jiaodu Technology, WeRide, Pony.ai, and EHang in the "AI + vehicle traffic" field. Guangzhou Radio Group, the "chief chain master" of Guangzhou' s AI industry chain, plays a leading role in guiding the ecosystem, organizing various chain master units of Guangzhou' s AI industry chain to create innovative application scenarios in their respective fields, driving the implementation of new AI scenarios.

Currently, Guangzhou has cultivated and gathered a large number of excellent AI enterprises such as Pony.ai, Zhijing Technology, Roots Interconnect, and XAG. AI is one of the six core metaverse technologies (IoT, blockchain, interaction, network and computing, AI, and electronic game technology), providing strong technical support for the metaverse. In the metaverse, AI promotes natural language processing, enabling seamless communication and overcoming language barriers. AI protects the metaverse by detecting and mitigating potential threats, ensuring safe and reliable virtual spaces. It analyzes massive amounts of data from user interactions, environmental simulations, and virtual economies, continuously learning and adapting to support the dynamic development of the metaverse. The industrial metaverse relies on powerful cloud computing, big data, and AI technologies to build comprehensive digital platforms that achieve intelligence, efficiency, visualization, and remote operation in industrial fields.

By leveraging AI' s virtual-real integration technology, the industrial metaverse seamlessly connects physical entities such as production equipment, production lines, and factories with virtual space, helping improve production efficiency, reduce costs, optimize resource allocation, and drive the development of intelligent manufacturing. Therefore, Guangzhou' s achievements in AI technology and industry provide strong support for industrial metaverse development and lay a solid foundation for the industrial metaverse to empower new industrialization. In October 2022, the Ministry of Industry and Information Technology announced the "AI Empowering Hundred Scenarios" list for national AI innovation application pilot zones, with Guangzhou having 14 AI application scenarios selected, ranking first in Guangdong Province. These included Guangzhou Siasun Robot Automation Company' s gas station robot intelligent refueling scenario, Guangzhou Radio and Television Information Security Company' s Shenshan Smart Highway digital twin system scenario, and Guangzhou Boyit Intelligent Technology Company' s manufacturing production process digital intelligence scenario. In the future, following the requirements of Guangzhou' s "Four Modernizations" Empowerment Platform Action Plan for Promoting High-Quality Manufacturing Development, Guangzhou will use the "Four Modernizations" (digitalization, networking, intelligence, and greening) empowerment platform as the starting point to create more application scenario benchmarks and promote the implementation of AI technology and products in Guangzhou.

(3) Guangzhou Has Built Advantageous Tracks in Industrial Internet

AI has brought the industrial internet into its "second half." Roots Interconnect' s industrial internet platform can perform real-time optimization and management of production from anywhere in the world, achieving full-factor transparency of machines, workers, materials, and environments, known as the "transparent factory." AI technology ensures global real-time connections and significantly reduces connection costs. Through big data modeling, it creates "digital twins" for equipment and achieves precise management and intelligent decision-making through AI vision and other technologies. Beyond manufacturing, Roots Interconnect, as the chain master enterprise of Guangzhou' s key industrial chain "software and information innovation," continues to empower multiple industrial clusters in Guangdong including small home appliances, customized home furnishing, textile and apparel, using new AI technologies to empower industry "intelligent manufacturing" upgrades. In 2023, Roots Interconnect released an industrial internet intelligent operating system for different scenarios, helping enterprises build smart factories and digital enterprises based on AI algorithms, as well as assisting leading enterprises and local governments in building intelligent industrial chain clusters.

On November 13, 2024, during the 2024 China (Jiangxi) Industrial Internet Innovation Development Conference and Platform Empowering SME Digital Transformation event, the Ministry of Industry and Information Technology officially announced the "2024 Cross-Industry and Cross-Domain Industrial Internet Platform Dynamic Evaluation Results," with 49 industrial internet plat-

forms selected. Among them, three platform companies are headquartered in Guangzhou: Guangdong Yixun Technology Company, Guangdong SIE Information Technology Company, and Roots Interconnect Company. Eight "dual-cross" industrial internet platforms have registered branches in Guangzhou: G-CREATE, Midea Cloud, Huawei FusionPlant, Tencent WeMake, Foxconn FiiCloud, Guangzhou Alibaba Cloud, Baidu Intelligent Cloud (Guangzhou), and iFLYTEK South China Company. Additionally, Guangzhou has dozens of professional (or characteristic) industrial internet platforms. These internet platforms serve as the digital foundation for implementing the "Four Modernizations" and advancing the industrial metaverse, currently providing intelligent services to tens of thousands of industrial enterprises in Guangzhou. Among them, G-CREATE was honored as one of the Top 30 Chinese Large Model Industry Emerging Enterprises in 2023. In August 2023, G-CREATE launched the OctopusGPT industrial intelligent large model engine base, designed to help industrial enterprises accelerate the realization of production and operation intelligence. Inspired by octopus biological characteristics, the model learns and simulates various rules and processes in industrial production to achieve comprehensive optimization and intelligent control of industrial production processes, helping industrial enterprises improve quality, reduce costs, and increase efficiency across R&D, production, supply, sales, service, and management scenarios.

(4) Digital Twins Empower Industrial Transformation and Support Smart City Construction

Enterprises in Guangzhou' s power, petrochemical, manufacturing, transportation, and other fields have begun exploring and applying digital twins, with some already operating maturely. Guangzhou Power Supply Company of State Grid uses digital twin technology to build digital twins of virtual power grids from information data streams in grid operations, perceiving and detecting physical power grid operation status, predicting grid development trends, and optimizing grid operation strategies. Manufacturing enterprises such as Midea Guangzhou Factory, BAIC Guangzhou Factory, and LG Electronics Guangzhou Factory apply digital twin technology throughout the entire lifecycle of industrial products, including design, production, testing, and maintenance. They perform R&D design operation verification to shorten R&D cycles and improve efficiency, simulate equipment operation status to achieve predictive maintenance and fault diagnosis, and optimize production lines.

Guangzhou Jiaodu Technology Company fully utilizes digital twin technology to achieve integrated dynamic perception mapping, online real-time rendering, and joint simulation deduction. This technology has been applied in traffic management, urban safety, and emergency management. Through strategic cooperation with Unity, a global leading 3D game engine provider (a real-time 3D interactive content creation and operation platform that enables creators across gaming, art, architecture, automotive design, and film to turn ideas into reality), Jiaodu Technology has successfully created a "three-dimensional spatial

baseboard" for refined urban governance and smart city construction, providing a solid foundation for urban development. Based on this baseboard, Jiaodu Technology has launched application platforms for different industries.

In the rail transit field, the company uses digital twin technology to achieve real-time monitoring and operation management inside stations, greatly improving operation and maintenance efficiency and enhancing training quality for technical personnel. Additionally, Jiaodu Technology has developed an "Urban Traffic Brain," "Video Cloud," and "Urban Emergency Brain" for urban transportation and smart city safety. Through joint simulation deduction and precise early warning decision-making, these technologies achieve highly realistic 3D maps, providing strong support for urban management. With its 硬核 technical capabilities, Jiaodu Technology is driving metaverse development in the B-end field.[8]

2.2 Districts Develop Industrial Metaverse with Distinctive Features

(1) Zengcheng District Focuses on Developing Metaverse-Related Technology Industries

According to the Zengcheng Economic and Technological Development Zone Industrial Development Plan (2023-2035), Zengcheng District is forward-looking in laying out new energy storage, intelligent equipment and robotics, AI and information technology, quantum technology, and metaverse industries, with the latter three being metaverse-related. In intelligent equipment and robotics, as an important area for Guangzhou' s development, Zengcheng District hosts enterprises such as Guangdong Hanhe Hanzu Robot, China Automotive Research and Testing Center, Bochuang Intelligent Equipment, and Guangdong Haiyu Intelligent Equipment. The district government has introduced multiple policy measures to strongly support the development of intelligent equipment and robotics industries. In AI and information technology, Zengcheng Development Zone has gathered a group of leading enterprises including Zengxin, Yuehai, Super Vision, and Visionox, forming a good industrial foundation. Among them, the Zengxin project is committed to building China' s first professional customized 12-inch intelligent sensor chip manufacturing enterprise, while Yuehai has 8-inch/12-inch TSV sensor packaging projects. Zengcheng District' s metaverse industry development is relatively active, having promoted the establishment of five industrial research institutes including the Metaverse Industry Academy and five Qiaomengyuan innovation and entrepreneurship stations including the Smart Home Standards Center.[9]

(2) Huangpu District Strongly Supports Metaverse Empowerment of Traditional Industries

In December 2021, the Greater Bay Area' s first metaverse research institute landed in Huangpu. Huangpu District focuses on "metaverse core industry chain + talent metaverse + enterprise metaverse + urban metaverse." As Guangzhou' s main engine for scientific and technological innovation and main front for

reform and opening up, Huangpu District released the Greater Bay Area' s first metaverse special support policy—the Guangzhou Huangpu District and Guangzhou Development Zone Measures for Promoting Metaverse Innovation and Development—in April 2022, focusing on digital twins, human-computer interaction, VR/AR/MR, and other fields. Additionally, it implements a "listing and ranking" system for metaverse key technologies, offering up to 10 million yuan in rewards for successfully conquered projects. As a core carrier area for China' s third integrated circuit pole, Huangpu District has a relatively complete metaverse ecological industry chain, with an industrial scale foundation exceeding 100 billion yuan.[10] In November 2023, the Greater Bay Area Metaverse Innovation Demonstration Center opened in Huangpu District, marking a new starting point for Huangpu' s metaverse industry. Huangpu District will target breakthrough and disruptive digital technologies and core equipment in metaverse technology as its main development track, support metaverse empowerment of traditional industries, and build a new highland for digital economy industry development.

(3) Nansha District Strives to Build a Metaverse Innovation Development Highland

Nansha District is forward-looking and quick to act, treating metaverse industry development as an important 抓手 for seizing new opportunities in the new round of scientific and technological revolution and industrial transformation. In March 2022, the Guangzhou Metaverse Innovation Alliance, co-initiated by Chenjing Technology, NetEase Smart Enterprise, 37 Interactive Entertainment, JiuDi Digital, and Daxizhou, was established in Nansha. The alliance aims to comprehensively enhance the strategic, systematic, and collaborative nature of the metaverse industry, accelerate the implementation of industrial metaverse, commercial metaverse, financial metaverse, educational metaverse, cultural metaverse, and big health metaverse applications, and build a metaverse consensus circle. In July 2022, the Nansha Metaverse Industry Agglomeration Area was officially unveiled, and Nansha released the "Nine Metaverse Measures." With enterprises moving in continuously, the agglomeration area has formed a preliminary clustering effect, with resident enterprises covering different links of the metaverse industry including underlying architecture, hardware equipment, digital models, and digital content, conducive to forming a metaverse industry ecosystem. By the end of 2023, 22 metaverse enterprises including Dingli Technology, FakeArt, and Guangdong Yongtai Technology had settled in.[11]

Nansha supports metaverse industry development from nine aspects: technology research support, innovation platform funding, industry agglomeration support, R&D investment subsidies, application scenario construction, innovation ecosystem building, talent introduction subsidies, technology finance support, and intellectual property promotion. Among them, for metaverse scientific research platforms with significant scientific and technological innovation support roles, each platform receives up to 200 million yuan in funding support, and

metaverse technology-based SMEs in the agglomeration area are provided with rent-free space for up to three years. Nansha District uses "eight measures" as the 抓手 to strive to build Nansha into a metaverse innovation development highland: establishing a metaverse innovation alliance, planning a metaverse industry agglomeration area, introducing a policy supporting metaverse innovation and development, building a metaverse application experience center, building a high-end metaverse research platform, establishing a metaverse venture capital fund, holding a metaverse innovation and entrepreneurship competition, and creating a batch of characteristic metaverse application scenarios.

15 Guangzhou Enterprises Enter China' s Metaverse Potential Enterprise List, Ranking Fourth Nationally

Data shows that in 2023, the hardware sector accounted for 83.89% of total investment and financing in the metaverse field.[12] The 2023 Hurun China Metaverse Potential Enterprises List identifies the 200 Chinese enterprises with the most development potential in the metaverse field. Among them, the Greater Bay Area has 50 enterprises listed, accounting for 25% of the national total. Guangzhou has 15 enterprises listed including 37 Interactive Entertainment, CloudWalk Technology, Aofei Data, GRG Banking Equipment, XPeng Motors, Focus Media, GAC Aion, and Zhongxu Future (in 2024, the Greater Bay Area had 54 enterprises listed; Guangzhou' s listed enterprises remained the same as in 2023, see Appendix 1), ranking fourth among Chinese cities. Among them, 37 Interactive Entertainment focuses on metaverse games and digital collections, CloudWalk Technology on 3D real-scene VR guidance technology, Aofei Data on data centers, GRG Banking Equipment on virtual digital humans and virtual banks, XPeng Motors on brand experience spaces, Focus Media on metaverse open communities, GAC Aion on product launch applications and intelligent connected vehicles, and Zhongxu Future on trendy gaming platforms.

(1) GAC Aion Provides Metaverse-Era Intelligent Vehicle Connectivity—5G+V2X

GAC Aion is a representative enterprise in Guangzhou' s scientific and technological innovation field and the core carrier of GAC Group' s "new four modernizations" transformation. The GAC Intelligent Connected New Energy Vehicle Industrial Park focuses on three major areas: "intelligent manufacturing + innovative R&D + automotive town," creating a "world-class automotive Silicon Valley" to showcase China' s new energy vehicle intelligent manufacturing strength to the world. Guangzhou also pioneered the "Four Modernizations" empowerment special action nationwide, cultivating "Four Modernizations" platforms for "digital transformation, networked collaboration, intelligent transformation, and green upgrading" to empower manufacturing transformation and upgrading. GAC Aion was the first in the industry to achieve large-scale customized production, with one new energy vehicle rolling off the line every 53 seconds. It is currently the most digitally and intelligently advanced production factory and ecological factory in the new energy vehicle industry, thus being selected as the first "Lighthouse Factory" in the new energy vehicle industry by

the World Economic Forum (WEF).

GAC Aion' s 5G+V2X intelligent connectivity technology not only enables system control between vehicles and between vehicles and infrastructure to meet intelligent driving scenario needs but also provides in-vehicle entertainment information, remote diagnostic services, shared mobility platforms, and other functions to enhance user experience and convenience, meeting intelligent life scenario needs. Additionally, the development of autonomous driving industries can provide solutions for problems that cannot currently be solved by single-vehicle intelligence. 5G+V2X has become an important direction for future automotive development. GAC Aion' s 5G+V2X technology will solve pain points in assisted autonomous driving. The benefits of 5G technology for intelligent electric vehicles are mainly reflected in three aspects: First, 5G technology empowers urban road application scenarios, accelerating autonomous driving development through V2X vehicle-road collaborative technology; second, it promotes intelligent cockpit development; third, it facilitates over-the-air software upgrades. Currently, the global connected vehicle industry ecosystem continues to enrich and improve, with the penetration rate of new vehicles equipped with intelligent connectivity functions exceeding 45% globally, expected to reach nearly 60% by 2025.[13] On April 7, 2024, Didi Autonomous Driving and GAC Aion jointly established a joint venture—Guangzhou Andi Technology Company —the first joint venture in China between an L4 autonomous driving company and a vehicle enterprise to create Robotaxi (autonomous taxi) mass-produced vehicles. Its first model has completed product definition and is undergoing joint review of design styling, with mass production planned for next year.[14]

(2) Midea Guangzhou Factory Creates an Intelligent Ecosystem Through the Industrial Metaverse

Located in Nansha District, Midea' s household air conditioner Guangzhou factory was named a "Lighthouse Factory" by the World Economic Forum (WEF). Midea Group was listed in the 2023 Hurun China Metaverse Potential Enterprises List. The group has applied industrial metaverse technologies including industrial simulation and digital twins, intelligent production scheduling, machine vision inspection, industrial robots, logistics robots, financial robots, industrial internet platforms, and digital twin parks to the Guangzhou Nansha factory, achieving remarkable results. On the production line, orange robots wave their mechanical arms to perform various processes, AGV robot trolleys on the ground flexibly shuttle between production lines carrying various raw materials and components, and aerial logistics tracks automatically transport semi-finished products to the next process. At the end of the workshop, there is also an "unmanned" area—the injection molding smart dark workshop, an intelligent automation unmanned zone where dozens of 2-meter-tall large KUKA robots quietly perform injection molding operations.

Since the factory began its intelligent manufacturing transformation and upgrading in 2016 and the automatic production line was built and put into operation, unit costs have been reduced by 14%, order delivery time shortened by 56%,

and labor efficiency increased by 28%. Since the industrial internet launched in 2018, the annual air conditioner output of Midea' s household air conditioner Guangzhou factory has increased from 3 million sets before the intelligent manufacturing transformation to 8 million sets currently. Midea has deeply embedded digitalization into its intelligent manufacturing industrial ecosystem. The Guangzhou Nansha Industrial Park produces 70-80% of its air conditioners for export, mainly to Europe, America, India, the Middle East, and other countries.

(3) Guangzhou Shipyard Uses VR/AR and Other Industrial Metaverse Technologies to Improve Ship Design Efficiency

In 2018, Guangzhou Shipyard International proposed the concept of "Digital Guangzhou Shipyard." By optimizing and improving informatization connectivity capabilities in R&D design, production manufacturing, and operation management, it has become a "pioneer" in digital transformation of ship manufacturing. Guangzhou Shipyard cooperated with Huawei (Nansha) AI Innovation Center, relying on Huawei Cloud digital diagnostic planning solutions to identify the crux of its digital construction, efficiently upgrade enterprise technical architecture, standardize data governance systems, and comprehensively sort out digital transformation strategic positioning and core development directions. After launching Huawei Cloud RPA process robots, by replacing manual completion of high-frequency, repetitive business in the financial center, the company helped reduce repetitive manual data management work by over 90%, shortening original data report processing work from over three days to within half an hour, improving efficiency by more than 20 times, further enhancing financial center office efficiency and quality, optimizing departmental workflows, and opening a new path for intelligent services in Guangzhou Shipyard' s business departments. On the other hand, Guangzhou Shipyard promotes the optimization and construction of R&D design platforms, resource integration platforms, intelligent manufacturing platforms, and integrated management platforms, helping various business departments and senior management fully perceive enterprise operation status, and through analysis, prediction, and algorithm models, assist enterprises in scientific decision-making, achieving automated, intelligent, and smart enterprise operations, effectively enhancing core competitiveness. Guangzhou Shipyard currently holds orders where over 60% are high-tech, high-value-added new green ship types with LNG dual-fuel and methanol dual-fuel power, which are inseparable from the continuous advancement of "green factory"construction. To further improve work efficiency, Guangzhou Shipyard' s R&D department uses VR/AR and 3D modeling technology for digital modeling of ship design, improving design efficiency.[15]

Since 2021, Guangzhou Shipyard International has successively explored various high-end, green ship type "tracks" including LNG dual-fuel oil tankers, car carriers, large container ships, and ice-breaking research vessels, with its LNG dual-fuel ships and car carriers ranking first globally in order holdings. It ranks as a domestic leader and world-class player in high-tech, high-value-added ship types such as liquid cargo ships, ro-ro passenger ships, semi-submersible ships,

research vessels, and polar vessels. By the end of October 2024, Guangzhou Shipyard International held over 84 ship orders with a total value exceeding 50 billion yuan, with delivery schedules extending to 2028. Among them, medium and high-end ship type orders account for over 90% of the total value. In the first half of 2024, operating revenue, main business profits, and business undertaking increased by 21.4%, 269.3%, and 25% year-on-year respectively, with various operating indicators exceeding scheduled progress, multiple tasks exceeding annual targets, and annual ship and marine delivery tasks completed ahead of schedule, achieving the best performance in nearly 10 years.[16]

(4) CloudWalk Technology Focuses on Core Technology, 37 Interactive Entertainment Invests in Related Fields

In early 2022, 37 Interactive Entertainment (stock code: 002555) launched China' s first metaverse game art museum, located in the metaverse art community Meta Bian. Users can control characters to tour the museum through VR glasses. With games as its main business, 37 Interactive Entertainment has penetrated the virtual human field: at its 14th anniversary celebration, the virtual character "Cong Mei" debuted and appeared as a host at the brand event. In March 2023, "Cong Mei" also received the first batch of digital resident certificates from Haizhu District, Guangzhou. 37 Interactive Entertainment also invests in other metaverse fields, involving upstream and downstream of the industrial chain such as AIGC, optical modules, AR smart glasses, VR/AR content, cloud gaming, spatial intelligence technology, and brain-computer interfaces, actively exploring various metaverse fields. In 2024, 37 Interactive Entertainment achieved operating revenue of 17.441 billion yuan, a year-on-year increase of 5.40%; net profit attributable to shareholders was 2.673 billion yuan, a year-on-year increase of 0.54% (Pan Jian, 2025).

CloudWalk Technology launched a human-machine collaborative open platform in Guangzhou as early as 2020. By connecting business data, hardware devices, and software applications, it enables AI to serve as infrastructure for the metaverse, laying the foundation for achieving "AI thinking and acting like humans." The company has made certain progress in metaverse core technology, AI ethical governance, and industry applications, and will further integrate metaverse and AI technology to enter a new stage of pragmatic development. On May 18, 2023, CloudWalk Technology held the "AI Empowering Digital China Industry Forum and 2023 CloudWalk Technology Human-Machine Collaborative Release Conference" in Guangzhou. The company cooperated with Huawei Technologies to launch the Ascend AI large model training and inference integrated machine, jointly creating large model integrated products. With its "AI Industry Elf," the company was successfully selected as one of China' s 50 most noteworthy AIGC (generative AI) enterprises. The company focuses on building a multimodal large model base and constructing a virtual digital human capability platform to provide low-cost and high-efficiency customized services for personalized needs in smart government affairs, virtual customer service, animation and gaming, and video creation industries. In manufacturing, CloudWalk Technol-

ogy, with Jiangsu Jinshiyuan Liquor Company as a seed customer, jointly built an intelligent manufacturing industry large model and supporting intelligent maintenance companion system, forming a replicable and promotable industry solution that will be widely applicable to production-oriented manufacturing enterprises, especially in new consumption and new energy fields.

(5) 16 Guangdong Enterprises Selected as National "Excellent-Level Smart Factories"

Smart factories are the main carriers of intelligent manufacturing and the main battlefield for digital transformation and intelligent upgrading of manufacturing. Six ministries and commissions including the Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Finance, State-owned Assets Supervision and Administration Commission of the State Council, State Administration for Market Regulation, and National Data Bureau jointly launched the 2024 Smart Factory Gradient Cultivation Action to support enterprises in building basic-level, advanced-level, excellent-level, and leading-level smart factories. In early 2025, the 2024 Excellent-Level Smart Factory list was officially released. To date, over 30,000 basic-level smart factories, more than 1,200 advanced-level smart factories, and over 230 excellent-level smart factories have been built nationwide. According to statistics, these excellent-level smart factories cover over 80% of manufacturing industry categories, building nearly 2,000 excellent scenarios including intelligent warehousing, online intelligent detection, product digital R&D design, intelligent production scheduling, and quality traceability and analysis improvement. "The average product R&D cycle has been shortened by 28.4%, production efficiency increased by 22.3%, defect rate decreased by 50.2%, and carbon emissions reduced by 20.4%, demonstrating remarkable quality improvement, efficiency enhancement, and carbon reduction effects, representing the leading level of digital transformation and intelligent upgrading of Chinese manufacturing enterprises." [17] Guangdong Province has 16 enterprises selected as excellent-level smart factories, including six in Guangzhou (see Appendix 2). These selected excellent-level smart factories have all adopted industrial metaverse-related technologies, representing new quality productive forces in the Greater Bay Area and indicating the future development direction of new quality productive forces in the region.

This list released by the Ministry of Industry and Information Technology and other departments is based on the Smart Manufacturing Capability Maturity Model (GB/T39116-2020). Selected excellent-level smart factories have reached level three or above in smart manufacturing capability, demonstrating their advancement in flexible production, informatization application, and intelligent levels. Smart factory selection not only recognizes enterprise production capabilities but also affirms enterprise intelligent transformation efforts. A large number of Guangdong enterprises entering the national excellent-level and advanced-level smart factory ranks will provide new momentum and direction for manufacturing digital transformation in the Greater Bay Area.

3.1 Reflections on the Industrial Metaverse Boosting Guangzhou' s New Industrialization Development

The 20th CPC National Congress Report states: "We must steadfastly focus the development of the economy on the real economy, promote new industrialization, and accelerate the building of a manufacturing powerhouse, quality powerhouse, aerospace powerhouse, transportation powerhouse, cyber powerhouse, and digital China." Currently, digitalization, networking, and intelligence are irreversibly changing human society and assisting manufacturing innovation and transformation.

(1) Using the Industrial Metaverse to Boost New Industrialization Development

Guangzhou should accelerate the digital transformation and change of manufacturing enterprises' entire business processes including R&D design, production manufacturing, operation management, and market services, continuously promoting in-depth digital intelligence transformation. The industrial metaverse will boost transformation and change in Guangzhou' s manufacturing enterprises, helping them integrate value-added services that bring market value around all aspects of the product lifecycle, boosting new industrialization development. The Ministry of Industry and Information Technology and seven other departments' Implementation Opinions on Promoting Future Industry Innovation Development (MIIT Joint Science [2024] No. 12) proposes: "Break through super terminals with explosive potential such as high-level intelligent connected vehicles and metaverse entrances, building new industrial competitive advantages." "Accelerate the promotion of emerging scenarios such as the industrial metaverse and biological manufacturing, driving manufacturing transformation and upgrading through scenario innovation." [18] This points out the direction for Guangzhou to use the industrial metaverse to assist manufacturing transformation and upgrading.

(2) The Industrial Metaverse as a New Frontier for Digital Economy Innovation and Industrial Chain Expansion

"The metaverse points to the 'ultimate form' of the internet, a more concrete 综合体 of the digital future, and a new frontier for digital economy innovation and industrial chain expansion. As the maturity of AR, VR, 5G, cloud computing, and other technologies improves and immersion, participation, and permanence are achieved, the metaverse will reconstruct social, lifestyle, and economic and social systems in the digital world." [19] Guangzhou should build a metaverse-centered industrial chain to seize the initiative in international competition. It should adhere to innovation-driven development, releasing metaverse integrated innovation momentum to drive cross-border integrated development of related technologies, and accelerate breakthroughs in metaverse key core technologies to promote industry acceleration toward high-end development. It should adhere to scenario traction, driving metaverse technology and product implementation through scenario construction, forming a high-level development situation where

demand pulls supply and supply creates demand.

3.2 Policy Recommendations

(1) Improve Top-Level Design and Strengthen Overall Coordination

First, improve the promotion system. It is recommended that municipal industrial information and science and technology management departments reasonably plan urban and district industrial metaverse development around the "five major improvement actions" of implementing large industries, large platforms, large projects, large enterprises, and large environments to promote high-end, intelligent, and green manufacturing development. Strengthen coordination among industrial, innovation, fiscal, financial, and regional policies, and jointly promote metaverse technology research, standard formulation, and governance system construction. Optimize industrial layout and promote metaverse technology innovation and industrial development according to local conditions. Support districts in researching and formulating implementation plans for the industrial metaverse in manufacturing, considering incorporating the industrial metaverse into the overall digital reform—digital economy system.

Second, accelerate research and formulation of laws, regulations, and standards. Encourage universities, research institutes, enterprise teams, and think tank experts to join the "Guangzhou Industrial Metaverse Alliance," focusing on research on industrial metaverse applications in manufacturing digital transformation and industrial asset ownership. Plan metaverse supervision regulations, focus on key issues such as technology enterprise monopolies, and improve the regulatory policy and standard system for promoting high-quality manufacturing development.

Third, explore an innovation-incentive policy environment. Establish and improve an inclusive, prudent, and flexible market access and regulatory environment. In terms of policy environment, Guangzhou has already gathered resources from all parties to promote the integration of the "four chains" of innovation, industry, capital, and talent. To urgently address enterprise funding needs, it should increase the intensity of "AI loan" special financing services, promote a batch of promising AI enterprises to go public, formulate and enrich the catalog of urgently needed and scarce talents for AI and metaverse industries, further improve talent introduction mechanisms, and build a national overseas talent offshore innovation and entrepreneurship base. Encourage local enterprises and research institutions to go global and deeply participate in global scientific research collaboration, encourage multinational companies and foreign research institutions to build metaverse-related technology R&D centers in Guangzhou, and promote joint technology R&D and industrial application between domestic and foreign enterprises.

(2) Construct Comprehensive Scenario Demonstrations

First, support regional pilot trials. Build and optimize the urban "industrial

brain," explore and excavate industrial metaverse scenarios, support the establishment of "scenario innovation promotion centers"with third-party institutions, and form a batch of replicable and promotable experience and practices.

Second, support enterprise innovation exploration. Encourage digital enterprises such as Tencent, Huawei, Foxconn Industrial Internet, Roots Interconnect, Midea Cloud, and G-CREATE to conduct industrial metaverse solution research with Guangzhou manufacturing enterprises. Leverage the demonstration and leading role of "lighthouse factories"such as Midea's Nansha Factory and intelligent manufacturing factories in the city. Support enterprises identified by the Ministry of Industry and Information Technology as "new generation information technology and manufacturing integration development demonstration" enterprises, including Guangri Elevator Industrial Company, Guangzhou Jifan Computer Company, Guangzhou Tech-Long Packaging Machinery Company, Guangzhou Jizhiyun IoT Company, Guangdong Tengyi Technology Company, and Foshan Jiyan Zhilian Company, to conduct scenario trial practices, striving to form a batch of solutions in key industries such as automotive, electronics, shipbuilding, textile and apparel, and food processing.

Third, actively layout industrial metaverse-related infrastructure. Guangzhou should deeply advance the construction of 5G, computing power infrastructure, industrial internet, IoT, connected vehicles, and gigabit optical networks, forward-looking layout key technology research on 6G, satellite internet, and direct mobile phone-to-satellite connections, and build a new type of digital infrastructure that is high-speed, ubiquitous, integrated, interconnected, intelligent, green, and safe and efficient. It should proactively organize research on advanced wireless communications, new network architectures, cross-domain integration, space-air-ground integration, and network and data security technologies, forming characteristic applications represented by holographic communications and digital twins. It should organize high-end industry-university-research institutions to jointly develop ultra-large-scale new intelligent computing centers, accelerate breakthroughs in cluster low-latency interconnect networks and heterogeneous resource management technologies, build ultra-large-scale intelligent computing centers to meet large model iterative training and application inference needs. It should also prepare and promote pilot applications of the third-generation internet in data exchanges, explore using blockchain technology to connect data across key industries and fields, research third-generation internet digital identity authentication systems, establish data governance and transaction circulation mechanisms, and form replicable and promotable typical cases.

(3) Build a Collaborative Agglomeration Ecosystem

First, build regional characteristic metaverse industrial parks. Support future (high-end) industry pilot zones and new industry platforms as carriers to gather a batch of upstream and downstream enterprises in the industrial metaverse industrial chain. Utilize Guangzhou' s advantageous electronics manufacturing industry to guide industrial development toward new terminals such as

VR/AR/MR/XR, forming new hardware, creating new products, and using new terminals to obtain new growth points for Guangzhou' s electronics manufacturing industry. Simultaneously, leverage the technical and talent strengths of leading gaming and cultural creative enterprises to build metaverse platform entrances, construct virtual world operating environments, create conditions for popularizing new terminals such as VR/AR/MR/XR, and build a foundation for metaverse industry development through software applications. Support Guangzhou industrial enterprises in exploring metaverse applications in digital transformation. On one hand, in six characteristic industry clusters including customized home furnishing, textile and apparel, beauty and daily chemicals, luggage and leather goods, jewelry, and food and beverages, explore digital twin technology applications in design, production, and service based on industrial internet platforms, creating a batch of "digital twin + personalized customization" benchmark enterprises. On the other hand, explore pilot construction of industrial metaverse platforms in the automotive industry, responsible for coordinating and maintaining automotive industrial metaverse platform construction and operation, providing platform support for digital transformation of the automotive industry.

Second, strengthen regional collaboration. Support the construction of a batch of cross-regional joint laboratories and key common technology platforms. It is recommended to enrich Guangzhou software park planning, designate separate areas specifically for metaverse software industry development and incubation, establish a metaverse software fund, and cultivate and support metaverse software industry startups.

Third, actively hold skill competitions, seminars, and exhibitions in the industrial metaverse field, gathering domestic and foreign expert talent and project resources, taking the lead in forming an industrial metaverse brand nationwide. Give full play to the role of relevant industry associations and other social organizations, promote advanced typical cases, and create a good atmosphere for advancing industrial metaverse development.

(4) Build a Technology Research System

First, research and establish municipal-level industrial metaverse or future industry science and technology special projects, support existing municipal key R&D plans to expand industrial metaverse technology special projects, and focus on formulating support policies for key technologies such as high-end chip manufacturing, 3D virtualization modeling and production tools, AI blockchain, and 6G high-speed communications.

Second, encourage joint technology research. The industrial metaverse is a systematic project; different universities, research institutions, and enterprise teams should be encouraged to form industrial innovation consortia to conduct joint integrated technology research.

Third, build a batch of industrial metaverse research institutions. Drawing on the experience of future industry research institute construction in devel-

oped countries and integrating regional new R&D institution construction models, encourage the building of cross-disciplinary, large-scale collaboration, high-intensity industrial metaverse collaborative innovation basic platforms.

(5) Seize Opportunities Brought by the Industrial Metaverse for New Quality Productive Forces Development and Build High-Quality Development Demonstrations

With the rapid development of technology, the metaverse, as an integrator of new-generation information technology, is gradually transforming from a science fiction concept into practical applications, leading a revolutionary wave of new quality productive forces. The metaverse simulates the real world and comprehensively reshapes future business, lifestyles, and value creation models. Industrial metaverse development promotes productivity improvement and production form transformation, exerting profound impacts on related industrial chains and value distribution models. The industrial metaverse drives top-down renewal of industrial chains, including hardware and software equipment updates and service model innovation. It makes connections between upstream and downstream industrial chains closer and management collaboration more efficient, reshaping industrial chains and value distribution models. In summary, the industrial metaverse revolution brings infinite possibilities and challenges for new quality productive forces development. We must fully recognize and grasp these possibilities, actively respond to and solve challenges, and promote the sustained and healthy development of the industrial metaverse in the Greater Bay Area. Only in this way can we better utilize metaverse technology to promote new industrialization construction in the Greater Bay Area and even the progress of human society.

The development of the industrial metaverse provides many possibilities for the progress of new quality productive forces. The integration of the two brings new development opportunities and challenges to all industries while promoting their own development. On one hand, the industrial metaverse provides diversified development directions for new quality productive forces; on the other hand, new quality productive forces strengthen the new momentum of virtual-real integration in the industrial metaverse. As one form of deep integration between digital technology and the real economy, the industrial metaverse is also a concept that continuously enriches, improves, and develops—a dynamically evolving system of digital survival that constantly discards the old and brings in the new.

The industrial metaverse is a new spatiotemporal dimension for deep integration between the digital economy and the real economy and a new path for manufacturing innovation and transformation. Guangzhou "must implement pillar and beam projects, cultivate and expand emerging industries such as intelligent connected new energy vehicles and biomedicine, forward-looking layout future industries such as humanoid robots and low-altitude economy, and promote the optimization and upgrading of traditional industries." [20] Guangzhou manufacturing enterprises should formulate practical and feasible transforma-

tion plans based on their digital technology application status and levels during digital transformation, and promote implementation step by step. They should actively explore establishing cross-regional and cross-platform collaborative innovation mechanisms for various industrial clusters, promote integration and sharing of regional innovation elements, build a regional digital development ecosystem with collaborative innovation, complementary advantages, and coordinated supply and demand in regional manufacturing, and enhance regional industrial chain supply chain collaborative supporting capabilities. They should consolidate the foundation for digital intelligence innovation and development in manufacturing and improve public service systems for standards, technology, talent, and capital.

In 2024, Guangdong' s emerging industries such as semiconductors and integrated circuits, low-altitude economy, intelligent robots, and new energy continuously achieved new breakthroughs, forming a batch of subdivided industrial clusters with leading comprehensive strength. Integrated circuit output increased by 21%. The low-altitude economy accelerated its takeoff, with DJI occupying over 80% of the global civilian drone market and EHang' s EH216-S becoming the world' s first eVTOL (Electric Vertical Takeoff and Landing) to obtain airworthiness certification "three certificates." In 2024, the added value growth of intelligent robot and high-end equipment manufacturing industrial clusters reached 32.9% and 6.4% respectively. "Guangdong has introduced an overall plan for future industry development, targeting 'seven major areas'including future intelligence, future life and health, and future energy to implement 'seven major projects.' The core industry scale of the AI field has reached 180 billion yuan, with computing power scale and enterprise scale ranking among the top nationwide." [21] The Guangdong Province Manufacturing Industry High-Quality Development Promotion Regulations clearly state: "Support higher education institutions, vocational schools (including technical schools), research institutions, and upstream and downstream enterprises in industrial chains to form industry-education integration communities. Support the construction of high-level vocational schools (including technical schools) and modern industrial colleges, and improve skill talent training models such as project-based, apprenticeship, and work-study alternation."

"The metaverse is not an endpoint but a development process—just like the slow process of adapting to one application after another year after year and gradually accepting a digital lifestyle. When we can replace real-world habits with corresponding digital methods, the metaverse will become more real (QuHarrison Terry et al., 2024)." [22] The industrial metaverse is a booster for developing new quality productive forces and achieving new industrialization in the Greater Bay Area. As long as government, industry, academia, research, and application work together to promote the industrial metaverse to empower manufacturing digital intelligence transformation and drive manufacturing toward green and high-end development, Guangdong' s manufacturing industry will surely become a demonstration area for high-quality development in the metaverse era and will certainly become a leading area for Chinese modernization in the Greater Bay

Area!

Appendix 1: 2024 Hurun China Metaverse Potential Enterprises List—15 Guangzhou Enterprises Listed

No.	Enterprise	Metaverse Specific Measures	Category	City
1	37 Interactive Entertainment	Metaverse games and digital collections	Ecological Application	Media & Entertainment
2	CloudWalk Technology	3D real-scene VR guidance technology	Underlying Technology	Software & Data Services
3	Aofei Data	Data center	Platform Technology	Software & Data Services
4	GRG Banking Equipment	Virtual digital human and virtual bank	Ecological Application	Software & Data Services
5	Jiaodu Technology	Digital twin	Underlying Technology	Software & Data Services
6	Focus Media	Metaverse open community	Platform Technology	Media & Entertainment
7	GAC Aion	Product launch application	Ecological Application	Automotive
8	Haige Communication	Motion simulation system	Underlying Technology	Software & Data Services

No.	Enterprise	Metaverse Specific Measures	Category	City
9	YY	Cultural media application	Ecological Application	Media & Entertainment
10	CVTE	Interactive intelligent technology	Underlying Technology	Software & Data Services
11	Vipshop	Virtual makeup try-on application	Ecological Application	E-commerce
12	Pony.ai	Visual computing	Underlying Technology	Automotive
13	XPeng Motors	Brand experience space	Ecological Application	Automotive
14	Zhidu Shares	Blockchain	Platform Technology	Software & Data Services
15	Zhongxu Future	NFT trendy gaming platform	Ecological Application	Media & Entertainment

Source: Hurun Report. 2024 Hurun China Metaverse Potential Enterprises List [EB/OL]. (2024-08-29)[2025-08-10]. https://www.hurun.net/zh-CN/Info/Detail?num=4CABSB7NNU34

Appendix 2: Ministry of Industry and Information Technology Excellent-Level Smart Factory (First Batch) Project Publicity List

Project	Enterprise
Integrated Energy and Environmental Control Smart Factory	China Science (Guangdong) Refining & Chemical Co., Ltd.
Refining Integration Cloud-Native Smart Factory	China National Petroleum Co., Ltd.
Digital Twin-Based Traditional Chinese Medicine Smart Factory	China Resources Sanjiu Medical & Pharmaceutical Co., Ltd.
Lithium Battery Product Full-Process Digital Intelligence Control Smart Factory	EVE Energy Co., Ltd.
Air Conditioner Product Full-Process Green and Low-Carbon Smart Factory	Guangdong Midea Refrigeration Equipment Co., Ltd.
Ultra-High-Strength Steel Lean Flexible Production Smart Factory	Baosteel Zhanjiang Iron & Steel Co., Ltd.
Air Conditioner Product Full Value Chain Efficient Operation Smart Factory	Guangzhou Hualing Refrigeration Equipment Co., Ltd.
High-End Elevator Full-Process Digital Intelligence Control Smart Factory	Hitachi Elevator (China) Co., Ltd.
Air Conditioner Product Green and Low-Carbon Smart Factory	Gree Electric Appliances (Zhuhai Jinwan) Co., Ltd.
Advanced Model-Driven High-End Optical Lens Smart Factory	Carl Zeiss Optics (China) Co., Ltd.
Multi-Dimensional Perception Collaborative Control Refining Smart Factory	China Petroleum & Chemical Corporation Guangzhou Branch
Power Battery End-to-End Quality Traceability Smart Factory	Inpai Battery Technology Co., Ltd.
Steel Prefabricated Components End-to-End Full-Process Digital Control	China Construction Steel Structure Guangdong Co., Ltd.
5G-Based Distribution Equipment Full Lifecycle Management	Guangzhou Baiyun Electric Equipment Co., Ltd.
Medical Equipment Full Lifecycle Quality Control Smart Factory	Shenzhen Mindray Bio-Medical Electronics Co., Ltd.

Source: Sina Finance. China Has Built Over 230 Excellent-Level Smart Factories, with Xiaomi, Li Auto, Seres, and Others Selected [EB/OL]. (2025-02-09)[2025-07-28]. https://finance.sina.com.cn/tech/digi/2025-02-09/doc-ineiwksh4809182.shtml

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Note: Figure translations are in progress. See original paper for figures.