

# A Survey on the Metaverse: The State-of-the-Art, Technologies, Applications, and Challenges

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**Abstract**—In recent years, the concept of the Metaverse has attracted considerable attention. This article provides a comprehensive overview of the Metaverse. First, the development status of the Metaverse is presented. We summarize the policies of various countries, companies, and organizations relevant to the Metaverse, as well as statistics on the number of Metaverse-related publications. Characteristics of the Metaverse are identified: 1) multitechnology convergence; 2) sociality; and 3) hyper-spatio-temporality. For the multitechnology convergence of the Metaverse, we divide the technological framework of the Metaverse into five dimensions. For the sociality of the Metaverse, we focus on the Metaverse as a virtual social world. Regarding the characteristic of hyper-spatio-temporality, we introduce the Metaverse as an open, immersive, and interactive 3-D virtual world which can break through the constraints of time and space in the real world. The challenges of the Metaverse are also discussed.

**Index Terms**—Hyper-spatio-temporality, metaverse, multitechnology convergence, sociality.

## I. INTRODUCTION

METAVERSE is composed of the words meta and verse (meta comes from Greek, a prefix meaning transcending, and verse means universe). It is a parallel world closely connected to the real world, the product of the development and integration of various technologies, the next stage of Internet development, and a virtual living space with social attributes. The current research on the Metaverse is a systematic assumption based on the trend of digitalization and virtualization given by the current technological development.

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The concept of the Metaverse originated from the assumption of a virtual world in literary works. A prototype of the Metaverse is considered to be a realistic virtual world described in the science fiction novel “Snow Crash” published in 1992. The Metaverse’s development represents the virtual world’s development to a certain extent. Dionisio et al. [1] proposed five stages in the evolution of virtual worlds, from those that initially existed only in literature and games to today’s immersive 3-D virtual worlds where users can create content independently.

Moreover, from a media perspective, the Metaverse is an open-source platform closely related to reality and the ultimate form of future development of digital media. Human communication technology and media are constantly improving. Reviewing the development history of human communication media (as shown in Fig. 1), the emergence of electronic communication has broken through time and geographical constraints, providing a more efficient way to communicate. The emergence and development of the Metaverse can expand the physical world into a world where reality and virtuality are integrated, reshaping the time and space of our existence. In the Metaverse, people will gain a new spatio-temporal experience. The Metaverse does not provide a single mapping of the real world, but a multidimensional, immersive virtual space [2] that transcends the traditional concept of spatio-temporality.

The Metaverse can map the physical world and provide interactive operation with the real world. The Internet of Things (IoT), digital twins, and other technologies promote the integration of the real world and the virtual world [4], which is the basis for building the Metaverse. As a new technology paradigm [5], IoT and its concepts and related applications (smart cities, logistics, and smart grids [6], [7]) have brought great benefits and changes to human production and life. The number of devices used in IoT is also multiplying [8]. The IoT enables real-time information exchange and interaction among heterogeneous devices [7], [9], increasing the amount of information available in applications, such as industrial production, city building, and health. IoT is an essential enabling technology for the digital twin [10], and the combination of IoT and digital twin technology helps to map the Metaverse onto the real world.

Blockchain, which originated from Bitcoin in 2008 [11], has significantly impacted business, society, politics, and other aspects since its development [12]. Blockchain can change existing business models and create new ones [12]. In addition to the financial industry, blockchain has also shown broad applications in many other fields [13], [14]. Blockchains

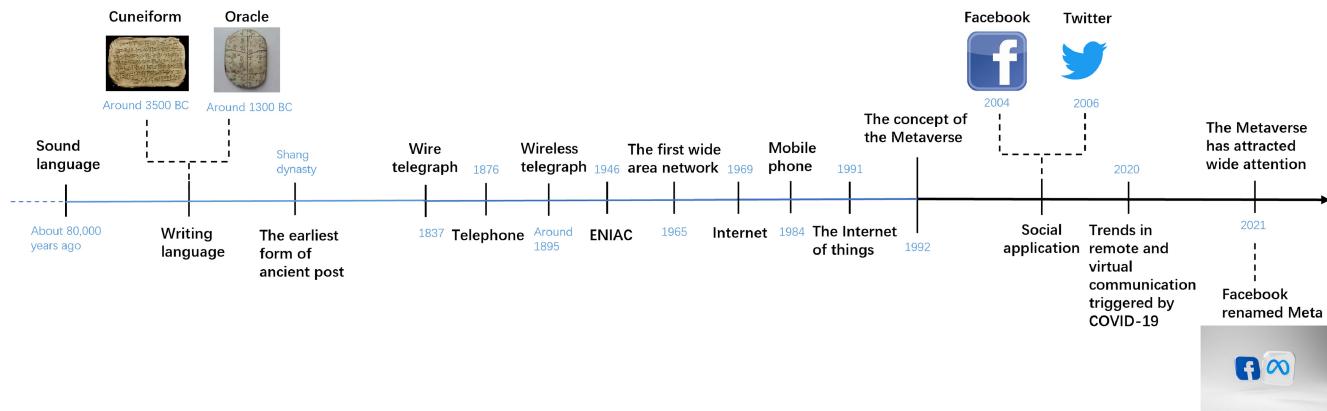


Fig. 1. Timeline of the development of communication methods [3].

use distributed databases that are decentralized, immutable, transparent, and verifiable. It offers advantages in speed, security, and availability, which can effectively ensure the security of transactions and the integrity of data [13]. Blockchain provides secure, anonymous services without compromising data integrity and without third-party control of transactions [11]. The many advantages of blockchain enable it to be extended to services and applications in many fields [11]. As the enabling technology of the Metaverse, blockchain is the pillar of the economic system in the Metaverse, which can help solve the problems of virtual assets and virtual identities [15], thereby providing users with rich consumption content.

We live in an era where the demand for mobile communication is rapidly increasing [16], and the development of wireless communication networks has dramatically improved our lives [17]. New communication technologies are the foundation for the development of the digital and communication industry [18], which can facilitate the development of existing other technologies and promote many new applications [16]. At the same time, the development and integration of new technologies have driven the continuous development of communication technologies. As new mobile communication technologies, 5G and 6G can further meet the network requirements of capacity, stability, low latency, and high speed and provide more innovative application services for many fields [19]. Compared with a 5G network, a 6G network has more advantages in performance [20]. The high demand for immersion, low latency, and real time in the Metaverse requires the support of a high-performance communication technology [21].

With the innovation and convergence of technologies, the Internet and its applications are constantly updated and have significant business prospects. As a new promising investment area, companies and enterprises are committed to the design of the Metaverse. In addition, from the user's perspective, there is an increasing demand for the freedom of the virtual world, the content of the Internet, and richer ways to interact. In 2021, the concept of the Metaverse came into the public eye. In March, Roblox included the Metaverse in its prospectus for the first time, proposing eight key features of the Metaverse. In October of the same year, Facebook announced the name change to Meta [22], the prefix of the word Metaverse. In addition,

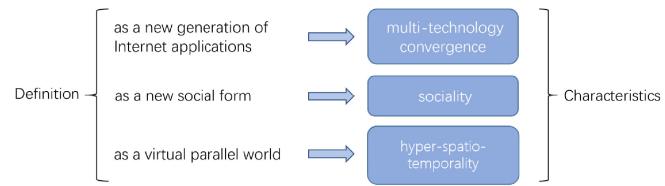


Fig. 2. Characteristics of the Metaverse.

various well-known companies and corporations have also outlined the Metaverse. Issues related to the Metaverse have received widespread attention, with technology, investment, countries, governments, and other fields showing continuous interest in the development of the Metaverse.

While bringing opportunities and development to society, the Metaverse will also face problems and challenges. In terms of enabling digital life, current interaction technologies, computing power, and communication technologies may not be able to support the Metaverse to function properly on a global scale. At the same time, issues, such as the compatibility and scalability of the Metaverse cannot be ignored. On the social level, as a virtual world closely connected to the real world, the economy in the Metaverse will profoundly affect the economy in the real world. As an extension and expansion of the human habitat, the Metaverse will also bring new ethical and moral issues to society. For individuals, the large amount of data in the Metaverse will increase the risk of invasion of privacy, and the high level of immersion provided by the Metaverse may increase the risk of cyber-syndrome (especially Internet addiction in adolescents) in users, causing physical and psychological harm [23], which will affect real life.

The Metaverse has the following three characteristics (as shown in Fig. 2). As a new Internet application, the Metaverse integrates a variety of new technologies and has the characteristic of multitechnology convergence; As a new social form, the Metaverse has the characteristic of sociality; As a virtual world that is parallel and closely related to the real world, the Metaverse has the characteristic of hyper-spatio-temporality.

The main contributions of this article can be summarized as follows.

- 1) This article comprehensively describes the development status of the Metaverse from three aspects: a) countries

- (relevant policies and markets); b) international organizations; and c) publications.
- 2) This article proposes and introduces three characteristics of the Metaverse: a) multitechnology convergence; b) sociality; and c) hyper-spatio-temporality.
  - 3) This article proposes the technical framework of the Metaverse. It consists of five parts: a) communication and computing infrastructure; b) management technology; c) fundamental common technology; d) virtual reality (VR) object connection; and e) VR space convergence.

The structure of this article is as follows: Section II presents the state of the art of the Metaverse. Based on the multitechnology convergence characteristic of the Metaverse, the technical framework of the Metaverse is proposed in Section III. In Section IV, various aspects of the Metaverse as a new form of society are presented in terms of the sociality characteristic of the Metaverse. In accordance with the hyper-spatio-temporality of the Metaverse, Section V presents the Metaverse as an open, immersive, and interactive 3-D virtual world. Moreover, the application fields of the Metaverse are summarized according to the current development trend of the Metaverse. Section VI discusses several problems that the Metaverse may need to address.

## II. RECENT ADVANCES OF THE METAVERSE

This section focuses on the development status (policies, companies, and products) of the Metaverse in different countries and the relevant policies of various international organizations, combined with the statistics on the number of Metaverse-related publications in the Web of Science database and the SCOPUS database, to analyze the development history and status of the Metaverse.

### A. Development Status of the Metaverse in Different Countries

This article introduces the development status of Metaverse in different countries from two aspects: 1) government policies/attitudes and 2) the market, as shown in Tables I and II. Among them, the government policies/attitudes part introduces the relevant policies of the Metaverse in different countries; the market part introduces the Metaverse industry layout and related products of representative companies from different countries.

### B. Guidelines of International Organizations

Since computer-related technologies, such as blockchain, artificial intelligence (AI), interactive technologies, cloud computing, and edge computing, are the supporting technologies for the Metaverse, this article presents the relevant guidelines of international organizations, such as ITU, IEEE, and IEF from a technical perspective. The guidelines of international organizations for Metaverse-related technologies are shown in Table III.

### C. Publications on the Metaverse

Web of Science is a Web-based multidisciplinary literature database. It is the world's largest comprehensive scientific

information resource covering most disciplines. It contains a variety of core academic journals that are the most influential in various research fields, such as natural sciences, engineering technology, and biomedicine. Therefore, we chose to count the number of Metaverse-related publications published in this database to analyze the development process. To validate the classification of the Metaverse development stages by the number of Metaverse-related publications published in the Web of Science database in this section, we also retrieved the number of Metaverse-related publications published in the SCOPUS database. Both databases are searched by topic (title, abstract, and keywords).

The search results are shown in Fig. 3. As of March 28th, 2023, a total of 2033 Metaverse-related publications have been published in Web of Science, and a total of 1566 Metaverse-related publications have been published in SCOPUS. From Fig. 3, the number of publications over the years, we can divide the development of the Metaverse into four stages: 1) embryonic stage; 2) primary stage; 3) ebb stage; 4) and development stage (as shown in Table IV).

The original concept of the Metaverse comes from the 1992 science fiction novel "Snow Crash" by Neil Stephenson. The first publication about the Metaverse on the Web of Science was published in 1998, which analyzed the current state of the real-time virtual human in the novel "Snow Crash," including appearance, clothing and accessories, body actions, etc., opening the curtain for studying the Metaverse. The 1999 film "The Matrix" depicted a world controlled by an AI computer system called "Matrix." In the Embryonic Stage, due to the lack of technical tools, literature, and art became the conceptual carriers of the Metaverse, such as movies and books.

At the beginning of the 21st century, the rapid development of VR technology and computer graphics created the technical foundation for the development of the Metaverse. Video games have become a new medium for the primary-level exploration of the Metaverse. The game Roblox, released by Roblox in 2006, and the development of Minecraft by Mojang Studios in Sweden in 2009 greatly inspired the first wave of discussions about the Metaverse.

The development of the Metaverse is still in its infancy, and the business model has yet to mature. Research interest in the Metaverse reached the Ebb Stage after 2013, as the development of the Metaverse is still limited by the current technology, such as interaction and computational power.

The year 2021 can be called "The Year of the Metaverse," and the Metaverse has regained a lot of discussion and attention in the technology and capital sectors. On 10 March 2021, sandbox gaming platform Roblox first included the concept of "Metaverse" in its prospectus and successfully landed on the New York Stock Exchange. On 28 October 2021, Facebook announced that the company would change its name to "Meta." In the Development Stage, Metaverse has already demonstrated its technological foundation to build and apply 5G, cloud computing, computer vision, blockchain, AI, and other cutting-edge science and technology to games, art, business, office, and many other fields. It is in a rapid development stage and shows unprecedented explosive power.

**TABLE I**  
**GOVERNMENT POLICIES/ATTITUDES IN DIFFERENT COUNTRIES**

Country	Government Policies/Attitudes
USA	<p>U.S. regulators focus on data security and privacy protection issues. To curb data misuse and privacy breaches, U.S. regulators have taken enforcement actions.</p> <p>In 2018, the Federal Trade Commission fined Facebook \$5 billion for consumer data breaches and imposed stricter privacy restrictions on the social media platform.</p> <p>In October 2021, U.S. senators from both parties proposed the “Government Ownership and Oversight of Artificial Intelligence Data Act”, which would require the regulation of data involved in federal artificial intelligence systems, especially facial recognition data, and would require the federal government to establish an artificial intelligence working group to ensure that government contractors can responsibly use biometric data collected by artificial intelligence technologies. This new regulation reflects the U.S. Congress’ cautious approach to technology involving private data and identification, and the Metaverse is a related technology concept.</p>
China	<p>The China Mobile Communications Association Metaverse Consensus Circle (CMCA-MCC) is directly under the umbrella of the China Mobile Communications Association. It is the convergence platform responsible for promoting the healthy and sustainable development of the Metaverse industry. CMCA-MCC was approved on October 15, 2021, making it the first Metaverse organization in China. On November 11, 2021, CMCA-MCC held an inauguration ceremony in Beijing, proclaimed November 11 as “Metaverse Day” and issued the “Metaverse Industry Declaration”. In March 2022, the logo of the Metaverse Industry Committee was registered as a copyright.</p> <p>On January 4, 2022, the Shanghai Municipal Commission of Economy and Information Technology issued the “14th Five-Year Plan for the Development of Shanghai’s Electronic Information Industry”, proposing forward-looking research and development to strengthen the basic capabilities of the underlying core technologies of the Metaverse. This is the first time the Metaverse has been included in the local “14th Five-Year Plan” industrial plan.</p> <p>On January 7, 2022, at the press conference on “Promoting the Development of the Capital in the New Era” held at the Fifth Session of the 15th National People’s Congress in Beijing, Wang Lei, the deputy director of the Beijing Municipal Bureau of Economy and Information Technology, stated that Beijing will promote the establishment of the Metaverse Innovation Consortium and explore the construction of the Metaverse Industry Clusters.</p> <p>On January 10 and 11, 2022, Hefei and Wuhan held their first meetings of the People’s Congress and included the Metaverse in their government work reports.</p> <p>On February 16, 2022, the Hongkou District in Shanghai released the “Metaverse Industry Development Action Plan” and inaugurated the Metaverse Industry Party Building Alliance in Hongkou District. The alliance is dedicated to building a Metaverse ecology with strong technical support, efficient result transformation, and rapid market application.</p>
Japan	<p>On April 1, 2017, Japan enacted the “Payment Services Act”, which officially recognizes Bitcoin as a legal payment method and sets precise regulatory requirements for the exchange of digital, encrypted assets. The Japanese economic authorities have defined the “Metaverse” but do not consider it a definitive form of business for now. The ministry plans to improve laws and development guidelines and is trying to take a leading position in the global virtual space industry.</p> <p>On July 13, 2020, the Ministry of Economy, Trade and Industry of Japan released the “Investigation Report on the Future Possibilities and Objects of the Virtual Space Industry” and made a survey report on the virtual space industry as a research topic.</p>
South Korea	<p>The South Korean government announced that it would cultivate 220 companies and 40,000 professionals specializing in the Metaverse technology in the future. A universal code of ethics will be established to ensure that the Metaverse operates in a trustworthy and healthy environment.</p> <p>At the end of 2020, the South Korean Ministry of Science, Information and Technology (MSIT) announced the “Immersive Economic Development Strategy”, which aims to make South Korea one of the top five countries in the world with extended reality.</p> <p>In May 2021, South Korea’s MSIT established the Metaverse Alliance, which aims to build a people-led Metaverse ecosystem through collaboration between government agencies and companies, and realize an open Metaverse platform in various real and virtual domains. The alliance has brought together over 500 companies and institutions, including Hyundai, Samsung, and SK Group.</p> <p>In July 2021, South Korea launched the “New Deal 2.0”. As part of the “Digital New Deal 2.0”, the Metaverse is listed as a key project for the development of the 5G industry, along with big data, artificial intelligence, and blockchain.</p> <p>In November 2021, the Seoul Metropolitan Government released the “Metaverse Seoul Five-Year Plan”, announcing that it will build a Metaverse administrative service ecosystem in all business areas of the city government in three phases starting in 2022. The three phases are: Inception (2022), Expansion (2023-2024), and Completion (2025-2026). As the first demonstration project, Seoul has held a virtual bell-ringing ceremony on the Metaverse platform to welcome the arrival of 2022.</p> <p>On Jan. 13, 2022, the Seoul Metropolitan Government said that it would invest 345.9 billion in 2022 cutting-edge digital technology projects such as the Metaverse, big data, and artificial intelligence, according to Yonhap News Agency. Of this amount, 112.6 billion won will be used for innovative urban projects that aim to improve public services by building digital infrastructure through the combination of the Metaverse, big data, and artificial intelligence technologies.</p>

The development stage division of the Metaverse is shown in Table IV. In addition, several existing survey papers on the Metaverse are compared with this article, and the main contents are shown in Table V. The differences between this article

and other papers are as follows: First, this article provides a comprehensive and detailed overview of current developments in the Metaverse, listing relevant policies in different countries and guidelines from international organizations and then

**TABLE II**  
COMPANIES AND RELATED PRODUCTS/SERVICES IN DIFFERENT COUNTRIES

Country	Company	Products/Services
USA	Roblox	In March 2021, Roblox, the “first stock of the Metaverse”, was officially listed on the New York Stock Exchange.
USA	Facebook	In its Q2 2021 financial report, Facebook announced that it would continue to invest in building the Metaverse at a rate of \$5 billion per year. On September 27, 2021, Facebook announced a \$50 million fund to develop the “Metaverse” platform. Formerly known as the XR Projects and Research Fund, the company said the fund would invest in projects and external research over two years. On October 28, 2021, at its annual conference called Facebook Connect, Facebook announced that it was changing the company’s name to “Meta”.
USA	EPIC Games	At the end of 2021, EPIC Games applied for the trademark “Megaverse”, which describes that in addition to being related to game content, it also combines various virtual reality applications, aiming to expand the layout of the Metaverse market. Tim Sweeney, CEO of EPIC Games, also plans to invest \$1 billion in the Metaverse content market. It is expected that “Fortnite” will not only link to various Metaverse applications, but also use its unreal engine to create other Metaverse applications.
USA	Microsoft	On January 18, 2022, Microsoft issued an official statement saying that it would acquire Activision Blizzard for \$95 per share in cash, a deal worth \$68.7 billion, including Activision Blizzard’s net cash. The acquisition will accelerate the growth of Microsoft’s gaming business across mobile, PC, console, and cloud and will help Microsoft build the Metaverse.
USA	NVIDIA	On November 9, 2021, at the 2021 GPU Technology Conference (GTC, 2021), NVIDIA announced a “three-core” strategy to upgrade the product route to “GPU+CPU+DPU”. At the same time, NVIDIA is positioning its newly released “Omniverse” platform as the “Engineer’s Metaverse”.
USA	ProShares	On December 28, 2021, U.S. Exchange Traded Fund (ETF) provider ProShares filed with the U.S. Securities and Exchange Commission (SEC) to launch a Metaverse-focused ETF called ProShares Metaverse Theme ETFs.
China	Tencent	In February 2020, Tencent participated in Roblox’s \$150 million Series G financing and has been the exclusive agent for Roblox’s product distribution in China. In addition, Tencent has applied for the registration of nearly 100 Metaverse-related trademarks, such as “Reverse War Metaverse”, “Tencent Music Metaverse”, “Peace Elite Metaverse”, “Oasis Qiyuan Universe”, “Wangzhe Metaverse”, and “Tianmei Metaverse”.
China	Alibaba	In September 2021, Alibaba released a new brand “Yuanjing” and launched a cloud game developer platform in October 2021. On September 8, 2021, virtual digital person AYAYI joined Alibaba and became the digital manager of Tmall Super Brand Day, which is Tmall’s further exploration of digital virtual marketing. On October 19, 2021, it was announced at the Yunqi Conference that an XR laboratory for AR, VR, and the Metaverse would be established under the Dharma Institute. On December 6, 2021, the wholly-owned subsidiary “Yuanjing Shengshi” was established. In addition, Alibaba has applied for the registration of a number of trademarks such as “Alibaba Metaverse”, “Taobao Metaverse”, “Dingding Metaverse”, “METAMEETING”, “METALEARNING”, and “Metaverse DINGTALK”.
China	NetEase	On January 27, 2018, NetEase released the product form and promotional video of the HoloKit AR glasses and launched the official website of the HoloKit developer community. On October 24, 2021, NetEase Fuxi officially released the immersive virtual conference system “Yaotai”, which created a new ancient immersive virtual conference world. On December 17, 2021, at the NetEase Future Conference: Metaverse Forum, NetEase announced that it would launch a global game UGC creator platform in the first quarter of 2022, which has been in beta for two years. In addition, NetEase applied for the registration of trademarks such as “NetEase Metaverse”, “Leihuo Metaverse”, and “Fuxi Metaverse”.
China	ByteDance	At the end of 2020, ByteDance and Lehua Entertainment jointly planned to launch a virtual girl group, A-SOUL. In August 2021, ByteDance acquired the VR company, Pico. In September 2021, ByteDance launched Pixsoul, a social product that allows users to create personalized avatars for social interaction. On January 5, 2022, the Metaverse’s social product “Party Island” was launched. In January 2022, ByteDance exclusively invested in “Li Weike”, an artificial intelligence avatar.
China	Xiaomi	On September 16, 2021, in the 2021 Game Industry Innovation Trend Forum, Xiaomi announced that it would make a comprehensive layout in cloud games, AR/VR, and the Metaverse. Cloud gaming is an essential first step for Xiaomi to deploy the Metaverse, and it has also become a key strategic direction in Xiaomi’s innovative business.

(Continued)

comparing the number of publications in the academic field over the years. Furthermore, by presenting the three characteristics of the Metaverse, the technical and nontechnical aspects of the Metaverse and the current definitions of the Metaverse at different levels are taken into account.

### III. METAVERSE: THE MULTITECHNOLOGY CONVERGENCE PERSPECTIVE

The Metaverse is a close interaction and combination of the real and virtual worlds, which requires the integration of various new technologies to create a new

**TABLE II**  
*(Continued) COMPANIES AND RELATED PRODUCTS/SERVICES IN DIFFERENT COUNTRIES*

Country	Company	Products/Services
China	JD	In April 2021, JD proposed the strategic idea of building an industrial Metaverse open platform to empower the real economy. On December 17, 2021, JD proposed the concept of “Industrial Metaverse” for the first time, focusing on the development layout and fundamental approach. JD built the OmniForce open ecological platform system, an integrated solution that provides developers with the replication, optimization, and transformation capabilities related to digital twins, consolidating the cloud base of the Industrial Metaverse.
China	Baidu	On December 21, 2021, Baidu announced the official targeted private beta test of the “Xi Rang” app, making it the first Metaverse-focused application.
China	HTC	During Mobile World Congress 2022 (MWC) (2022.2.28-2022.3.3), HTC officially announced the Metaverse brand Viverse and introduced new Metaverse products, platforms, and applications.
Japan	Avex	Avex Business Development and Digital Motion established the “Virtual Avex Group”, which plans to promote existing animation or game characters, host virtual artist activities, and virtualize concerts by real artists and other activities.
Japan	Sony	On January 31, 2022, Sony Interactive Entertainment announced that it would acquire Bungie, the developer of the famous American game “Destiny”, for \$3.6 billion.
Japan	Cluster	Cluster has launched a Metaverse platform where players can create avatars, socialize, and attend virtual concerts. Naoto Kato, CEO of Cluster, elaborated on the business format of the Metaverse and presented ideas and opinions such as “establishing a virtual Shibuya”, “establishing a 3DCG ecosystem”, “establishing a Metaverse laboratory”, and “Japan should incorporate the game industry into the national strategy”.
Japan	GREE	In August 2021, GREE, the Japanese mobile social game platform company, announced an investment of 10 billion yen to join the Metaverse business, which aims to attract hundreds of millions of users worldwide in two to three years. REALITY, a subsidiary of GREE, is the primary operator of its Metaverse business. REALITY’s mobile virtual live broadcast software “REALITY” currently provides mobile virtual live broadcasting services in 63 countries and regions around the world, providing virtual live broadcasting experience to millions of people.
Japan	Fugu.finance	Fugu.finance has created Japan’s first IP distribution platform for the Metaverse series. The platform is based on the BSC chain development and collects Japanese high-quality artist IPs. Through the whole network cross-chain model and the unique GameFi game, Non-Fungible Token(NFT) artwork transactions are realized in the Metaverse.
South Korea	Samsung	On November 9, 2021, Samsung Electronics, a subsidiary of Samsung Group, announced that it has successfully developed the industry’s first 14nm-based next-generation mobile dynamic random access memory - LPDDR5X (Low Power Double Data Rate 5X). The product has dramatically improved speed, capacity, and power-saving features and will promote the development of industries such as 5G, artificial intelligence, and the Metaverse. In addition, Samsung Display, a subsidiary of Samsung Group, and LG Display, a subsidiary of LG Group, plan to enter the Metaverse market by focusing on self-luminous displays such as OLEDs.
South Korea	NAVER	On March 1, 2018, NAVER launched the Metaverse platform ZEPETO. This virtual social application allows users to create 3D avatars regardless of age, gender, race, etc., and communicate with users around the world in a virtual reality experience. On September 4, 2020, the ZEPETO platform hosted a virtual autograph session for the Korean idol group BLACKPINK, which was viewed by over 40 million people. ZEPETO also launched virtual products with fashion brands such as Gucci and Nike.
South Korea	SK Group	On July 15, 2021, SK Telecom, a subsidiary of SK Group, launched “ifland”, a Metaverse platform focusing on social VR and virtual meetings. Users can use virtual avatars on this platform to hold events in specific online scenarios for social and recreational activities.
South Korea	Kakao	On October 25, 2021, Kakao Entertainment, a subsidiary of Kakao, announced that it would invest 12 billion won in Metaverse Entertainment, a subsidiary of Netmarble Games. The two parties will work together to launch a virtual idol group. Metaverse Entertainment also plans to combine Kakao Entertainment’s webcomics, web novels, and other IP resources with Netmarble’s game characters to carry out various character-related Metaverse projects. On June 7, 2022, Kakao announced its two-track Metaverse strategy based on text and virtual worlds. In addition, its subsidiary Friend Games develops an NFT trading platform specializing in sports and game content.
South Korea	Com2Us	On December 29, 2021, Com2uS released a teaser and prototype demo video of its Metaverse platform “Com2Verse”, which it calls a “giant integrated mirror world and Metaverse platform”.
South Korea	AfreecaTV	AfreecaTV, a South Korean online live and streaming service, has launched an NFT trading platform called AFT Market.

form of Internet application and society. This section outlines the technologies involved in the Metaverse, as shown in Fig. 4. The technical framework of the Metaverse

is divided into five parts: 1) communication and computing infrastructure; 2) management technology; 3) fundamental common technology; 4) VR object connection;

TABLE III  
GUIDELINES OF INTERNATIONAL ORGANIZATIONS

International Organization	Policy
ITU	In August 2020, the ITU published the first set of international standards for blockchain. The ITU held a plenary session from April 19 to 30, 2021. At the meeting, three proposals for international blockchain standards led by the Chinese Academy of Information and Communications Technology were approved. From February 23 to March 2, 2016, the 23rd meeting of the ITU Working Group was held in Beijing. The Chinese Academy of Information and Communications Technology was the Chinese sponsor. The ITU is evaluating 5G technology and exploring a new spectrum for mobile communications.
IEEE	On December 6, 2017, the establishment of the IEEE Blockchain Asset Transaction Committee was officially approved. On December 23, 2020, the “IEEE Standard for Blockchain System Data Format” was officially released and implemented under the leadership of the China Electronics Technology Standardization Institute. According to “IEEE Global CIO and CTO Interview Survey: Opportunities and Challenges in 2021, and Key Technology Trends”, its findings show that artificial intelligence and machine learning, 5G, and IoT technologies will be the essential technologies in 2021 and beyond.
IET	IET Blockchain was launched in collaboration with the IET, Tongji University, and the Shanghai Blockchain Application Shanghai Engineering Research Center for Blockchain Application and Services (SERCBAAS). It aims to publish cutting-edge results on blockchain fundamental theories, applied technology and industrial development, technological innovation, and the latest views.
WWW	On June 8, 2016, the first Decentralized Web Summit was held in San Francisco, USA. Tim Berners-Lee, the inventor of the WWW, mentioned at the conference that blockchain and P2P technology would be used to create a decentralized internet. The World Wide Web Consortium (W3C) held a blockchain seminar and called for the creation of public standards for blockchain technology.

TABLE IV  
DEVELOPMENT STAGE DIVISION OF THE METAVERSE

Period	Stage	Description	Total Number of Publications		Annual Average Number of Publications	
			Web of Science	Scopus	Web of Science	Scopus
1995-2006	Embryonic Stage	Mainly based on literature and art.	5	13	0.42	1.08
2007-2013	Primary Stage	Mainly based on video games.	96	108	13.71	15.43
2014-2020	Ebb Stage	Restricted by many unresolved issues.	45	61	6.43	8.71
2021-2022	Development Stage	Integration of multiple technologies to achieve multifield applications.	1638	1090	819	545

and 5) VR space convergence. The details are explained below.

#### A. Communication and Computing Infrastructure

Whether performing large-scale computational tasks remotely, accessing large databases, or providing shared experiences among users, they are inextricably linked to networks and communications [27]. 5G and 6G technologies are the communication foundation of the Metaverse. 5G has the advantages of high speed, low latency, ubiquitous networks, low power consumption, and interconnection, which make it possible to realize the Metaverse. 6G will break the boundaries of reality and extend the service objects of people, machines, and things in the physical world to the environment of the virtual world, and provide the network foundation for the Metaverse by connecting the physical and virtual worlds and realizing a cooperative human-machine-thing environment.

In 5G and 6G network environments, quantum communication ensures secure communication in the Metaverse. Chowdhury et al. [28] proposed that quantum communication

provides high security by applying quantum keys based on the quantum noncloning theorem and the uncertainty principle. In addition, quantum communication improves the overall security due to the superposition property of quantum bits.

In addition, the IoT plays a vital role in the network infrastructure of the Metaverse. IoT sensing provides users with an authentic, persistent, and seamless interactive experience that bridges the Metaverse and the real world. However, there are still problems—for example, the imbalance between data explosion and the limited sensing resources. Shi et al. [29] proposed the solution of selective perception. Another obstacle is the poor performance of the sensor/actuator. To address this issue, Ning and Liu [30] proposed that Nanotechnology can improve the performance of sensors/actuators (e.g., higher sensitivity and selectivity, shorter response time, and longer lifetime). Therefore, the application of nanomaterials (e.g., graphene, nanowires, etc.) will provide Metaverse sensing and communication capabilities.

Building the Metaverse requires a robust computing system. Current computing architectures cannot yet support the low usage threshold and high immersion requirements of the

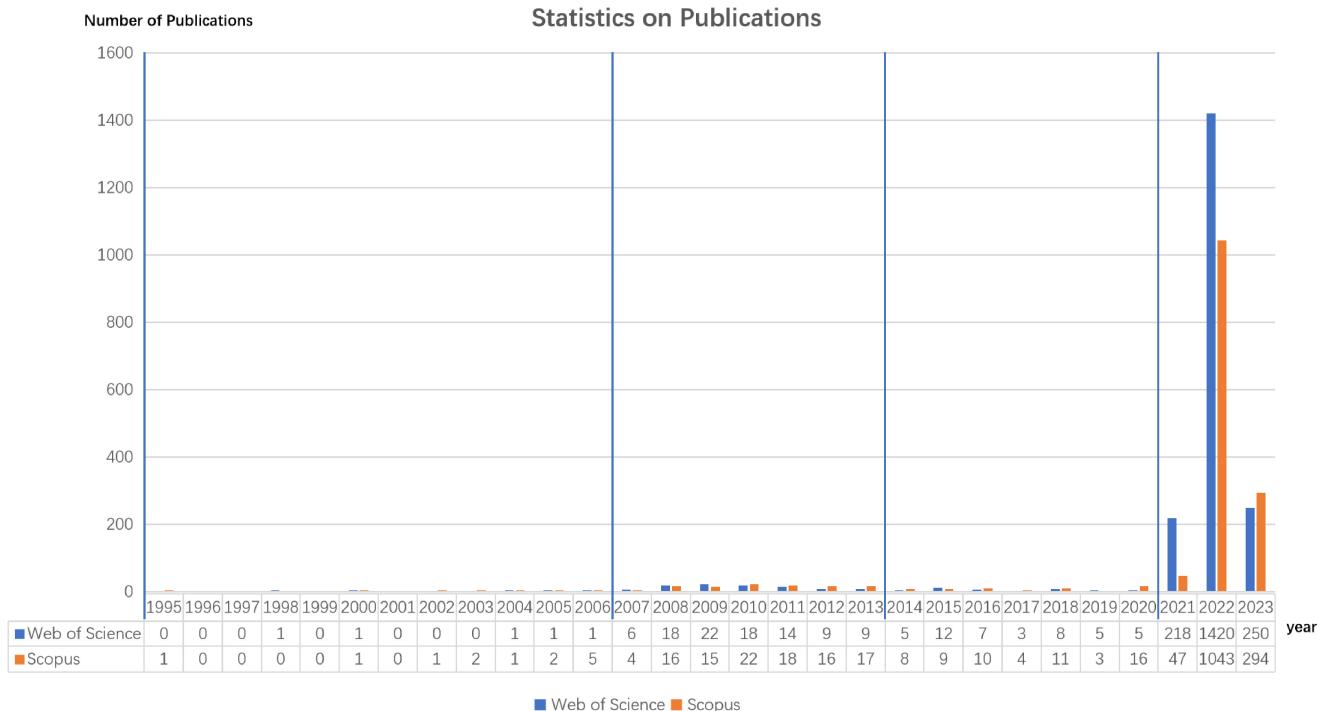


Fig. 3. Statistical chart for the number of publications in Web of Science and Scopus.

TABLE V  
COMPARISON TABLE BETWEEN DIFFERENT SURVEY PAPERS

Title	Year	Main Work	Summary
3D virtual worlds and the metaverse: Current status and future possibilities [1]	2013	<ul style="list-style-type: none"> <li>The Metaverse is defined as the latest stage of the development of the 3D virtual world, which is a substitute for human social and cultural interaction.</li> <li>The five stages of virtual world development are introduced.</li> <li>The four features of the Metaverse, namely, realism, ubiquity, interoperability, and scalability, are proposed and introduced.</li> </ul>	The focus is on the development of IoT and Cyber-Physical Systems, and The Metaverse is introduced as the latest stage.
The Metaverse as Mediator between Technology, Trends, and the Digital Transformation of Society and Business [24]	2018	<ul style="list-style-type: none"> <li>The Metaverse is defined as a global virtual world and computing infrastructure, which is regarded as the future trend of developing related technologies (Internet of Things, Cyber-Physical Systems) of physical and virtual integration, and will be applied to the social and commercial fields.</li> </ul>	Focus on the development of IoT and Cyber-Physical Systems, and The Metaverse is introduced as the latest stage.
Metaverse for Social Good: A University Campus Prototype [25]	2021	<ul style="list-style-type: none"> <li>The three-layer architecture of the Metaverse, including infrastructure, interaction, and ecosystem, is proposed and introduced.</li> <li>The prototype of the Metaverse on campus is introduced.</li> </ul>	Focus on the architecture of the Metaverse, and a prototype is introduced.
A Metaverse: Taxonomy, components, applications, and open challenges [26]	2022	<ul style="list-style-type: none"> <li>The Metaverse is introduced in three parts (hardware, software, and content) and three methods (user interaction, implementation, and application).</li> </ul>	Focus on the architecture and components of the Metaverse.
A Survey on the Metaverse: the State-of-the-Art, Technologies, Applications, and Challenges (this paper)	2023	<ul style="list-style-type: none"> <li>The development status of the Metaverse is introduced from three aspects: the state (policy and market), international organizations, and publications.</li> <li>Three characteristics of the Metaverse are proposed and presented.</li> <li>The technical framework of the Metaverse is proposed and introduced from five parts: communication and computing infrastructure, management technology, fundamental common technology, virtual reality object connection, and virtual reality space convergence.</li> </ul>	Focus on the existing results and technical framework of the Metaverse.

Metaverse. However, cloud computing, edge computing, and other computing paradigms can drive computational power [31], [32] and serve as the technological foundation for the Metaverse. In [33], an approach called CoPace is proposed with the goal of collaborative computational offloading and content caching. In [34], a computational offloading and resource management approach called PCORA is proposed for dynamic mobile edge computing environments. In [35],

a task offloading and resource allocation scheme based on game theory and reinforcement learning, called TORA, is proposed.

#### B. Management Technology

The management technologies of the Metaverse provide the environment necessary for the interconnection and convergence

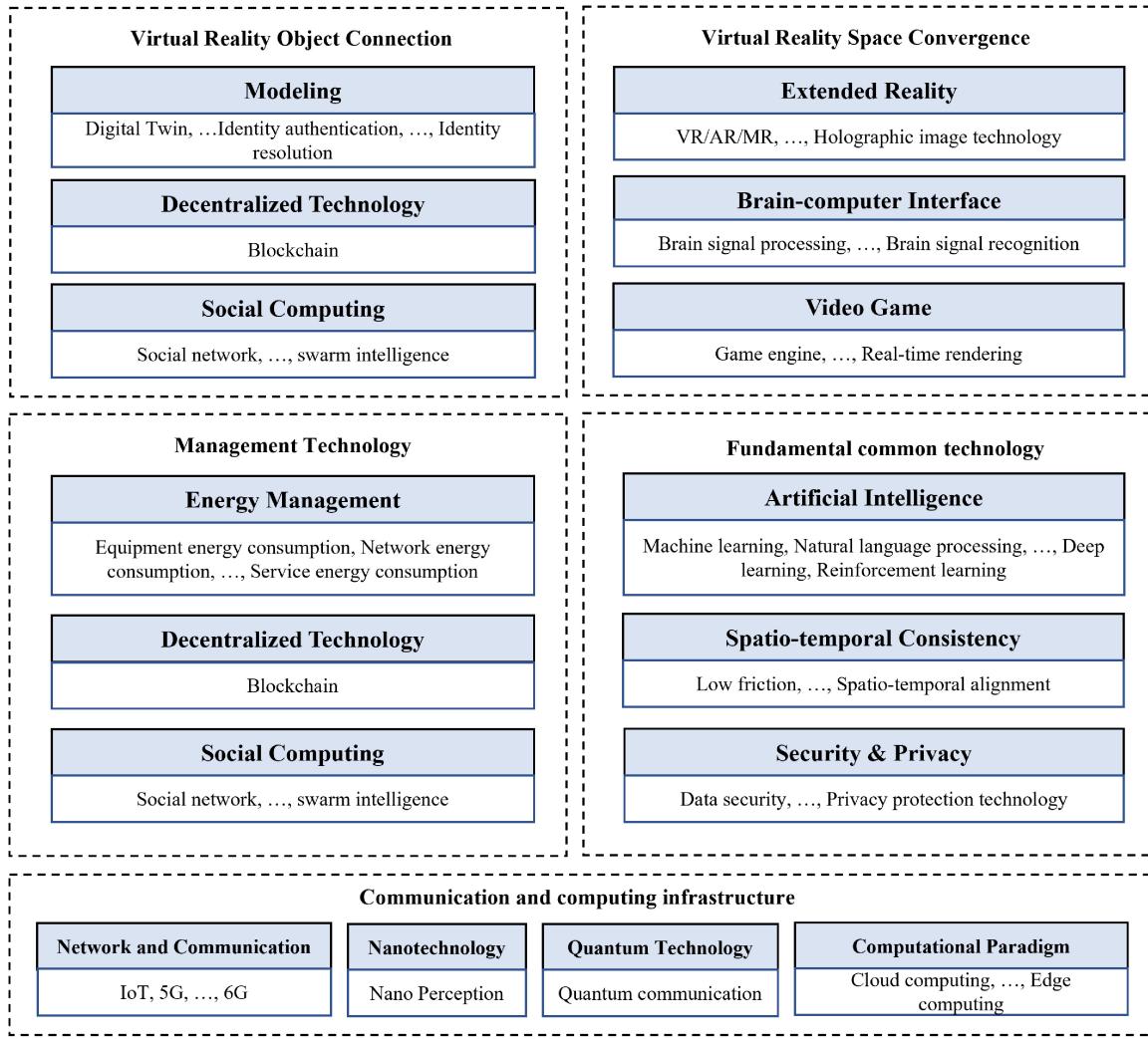


Fig. 4. Technology roadmap of the Metaverse.

of the real and virtual worlds, mainly, including energy management, resource management, and session management.

The first consideration in energy management technology is the electrical energy consumption by the Metaverse architecture and facilities. Many researchers have proposed methods for energy monitoring. For example, Krishnamoorthy et al. [36] proposed an IoT-based method to monitor load consumption and efficiently save energy. Bedi et al. [37] developed an Elman recurrent neural network model and an exponential power prediction model to reduce power loss and save costs. The medium- and long-term development of the Metaverse requires the search for more stable and sustainable energy. Energy sustainability is not only the core constraint of the Metaverse, but also an investment opportunity.

An urgent problem to be solved in the context of the Metaverse's resource management technology is the efficient discovery and allocation of resources. Researchers are also constantly exploring resource management strategies as a foundation for the implementation of the Metaverse. Nunes et al. [38] proposed a resource search and discovery algorithm based on elimination selection to solve the

problem of resource search and discovery in heterogeneous environments. Moorthy and Pabitha [39] proposed a novel cloud resource discovery mechanism based on a sine-cosine optimization algorithm. Han et al. [40] proposed a dynamic resource allocation framework to synchronize the Metaverse with IoT services and data.

Session management manages the interaction between ubiquitous resources and resource users in heterogeneous networks [30]. In the Metaverse, it is essential to manage persistent interactions with dynamic characteristics in a Metaverse environment for sessions with multiple resource users. Moreover, the real-time nature of the session is available to enhance the immersion experience of the users. Park and Soyer [41] discussed the realization of high-performance session management for users in a 5G wireless network environment. In addition, the Metaverse should also prevent sessions from being attacked. Nadar et al. [42] studied a defensive approach against destructive authentication and session management attacks. Perrin and Marlinspike [43] developed the sesame algorithm to encrypt asynchronous messages and improve session security.

### C. Fundamental Common Technology

The fundamental common technologies of the Metaverse comprise AI, spatio-temporal consistency, security, privacy, etc. The details are as follows.

AI algorithms (i.e., machine learning, deep learning, reinforcement learning, etc.) are the “keys” that connect the virtual and real worlds. The three elements of AI, namely data, algorithms, and computing power, play a crucial role in the construction and development of the Metaverse. Through AI technologies, the Metaverse can safely and freely build social and economic activities outside the real world [44]. Computer vision, intelligent speech, natural language processing, and other technologies can provide users with visual and auditory sensations close to real life.

Spatio-temporal consistency is the fundamental element of the Metaverse. The ultimate form of the Metaverse is the parallel digital spatio-temporal continuum of real human society, so consistent spatio-temporal data is critical for mapping between the real world and the Metaverse. Atluri et al. [45] have explored the approaches of spatio-temporal data mining. It is also necessary to study spatio-temporal consistency methods, such as time synchronization, target positioning, time registration, and spatial registration [30].

The security and privacy of user data are among the most significant issues in the real world. With the advent of the Metaverse, the amount and richness of personal data collected are unprecedented. Different companies and organizations will create one or more Metaverses in the future. Therefore, issues, such as data coordination between different companies/organizations and different Metaverses, privacy, and security of the Metaverse need to be considered. Zhang et al. [46] reviewed the literature on user access authentication, network situation awareness, dangerous behavior monitoring, and abnormal traffic identification to provide a reference for optimizing security and privacy in the Metaverse. Falchuk et al. [47] also proposed the privacy issues in the Metaverse.

### D. Virtual Reality Object Connection

The Metaverse is inextricably linked to modeling technologies, decentralization technologies, and social computing. As a virtual world parallel to the real world, the Metaverse must digitally reproduce physical entities and create a digital representation of real things. Users entering the Metaverse need an identity; therefore, digital twins, identity modeling, and identity addressing [48] are the bridge between the real and virtual worlds and an important research area of the Metaverse.

As a new form of society, the Metaverse cannot exist without social computing. The emergence of the Metaverse will not make virtual social relationships replace real-world social relationships, but will bring a new type of social relationship that combines online and offline. Social computing predicts the operation and trends of the Metaverse by studying human behavior and social relationships. In addition, it is easier to collect information, such as location, age, and users’ preferences in the Metaverse and make detailed evaluations to better support the Metaverse society.

The Metaverse adheres to the concept of decentralization and requires the help of decentralized underlying technologies to ensure the security and operation of the Metaverse. Decentralized technologies include blockchain, distributed storage, distributed computing, etc. Ryskeldiev et al. [49] proposed a point-to-point distribution model based on distributed blockchain for the virtual space of mixed reality (MR) applications.

### E. Virtual Reality Space Convergence

Augmented reality (AR), VR, MR, brain–computer interface (BCI), and video games are the technologies that are essential to achieve the integration of the virtual and real worlds in the Metaverse.

The AR/VR/MR technology is one of the technological pillars upon which the Metaverse is built. AR superimposes virtual information on a location through device recognition and evaluation (2-D, 3-D, GPS, somatosensory, facial, etc., detected objects) and displays it on the device’s screen, enabling virtual information to be interacted with in real time. VR is an advanced, idealized system that provides users with a fully immersive experience that makes them feel as if they are in the real world. MR is a new visualization environment that merges the real and virtual worlds. It allows physical and digital objects to coexist and interact in real time. The boundaries between VR/AR/MR will become blurred and evolve into a converging technology in the future. Currently, VR/AR/MR is the primary interaction technology used by Metaverse to create a highly interactive virtual world for users.

The holographic image is a recording and reproduction technology that presents a 3-D image of an object by optical means. It is the result of a combination of computer and electronic imaging technology that uses coherent light interference to record the amplitude and phase information of light waves and obtain all information about the object, including shape, size, etc. The hologram image is 3-D, and the user can view the image from different angles with the naked eye without the need for a portable device. With the development of this technology, the boundary between the physical world and the virtual world will become blurred, contributing to the realization of the Metaverse.

BCI can accurately identify brain signals during brain activity, then encode and decode them. Users can use these signals to perform operations, such as playing games, typing, etc. BCI connects the human neural world to the external physical world by decoding individual brain signals into commands recognized by computing devices [50], thus enabling the spatial interface between the virtual world and the real world. Abiri et al. [51] reviewed the electroencephalography (EEG)-based BCI approach. Currently, there are also studies on BCI based on AI techniques [50], [52], [53] to accelerate the development of BCI and to lay the foundation for space convergence of the Metaverse.

The video game technology is the most intuitive way to present the Metaverse. It can provide a creative platform for the Metaverse and realize the aggregation of interactive content and social scenes. The game engine is the core of the

TABLE VI  
OVERVIEW OF REPRESENTATIVE GAME ENGINES

Engine Name	Company	Release Time	Application Game and Link
Unreal Engine	Epic	1998	War Machine, Quality Effect, Ownerless Land, Absolute Survival, Escape, Peace Elite, Fortress Night, etc. <a href="https://www.unrealengine.com/">https://www.unrealengine.com/</a>
Rockstar Engine	Rockstar	1998	GTA4, Wild Escort <a href="https://www.rockstargames.com/">https://www.rockstargames.com/</a>
Unity Engine	Unity Technologies	2004	Glory of the King, Legend of Hearthstone, Temple Escape, etc. <a href="https://www.unity.com/">https://www.unity.com/</a>
Source Engine	Valve	2004	DoTA2, Anti terrorism Elite, The Fall of Titan, The Road to Survival <a href="https://www.moddb.com/engines/source/">https://www.moddb.com/engines/source/</a>
IW Engine	Infinity Ward	2005	Call of Duty, Call of Duty: Black Action 3 <a href="https://www.moddb.com/engines/iw-engine">https://www.moddb.com/engines/iw-engine</a>
Frostbite Engine	DICE	2006	Battlefield, Medal of Honor, etc. <a href="https://www.ea.com/frostbite">https://www.ea.com/frostbite</a>
Anvil Engine	Ubisoft Montreal	2007	Assassin's Creed, Prince of Persia 4 <a href="https://www.moddb.com/engines/scimitar">https://www.moddb.com/engines/scimitar</a>
Cry Engine 3	CRYTEK	2009	Island Crisis, Sniper: Ghost Warrior 2, Monster Hunter <a href="https://www.cryengine.com/">https://www.cryengine.com/</a>
Cocos2D	-	2010	Defending Radish, Fishing Expert, My Name is Mt <a href="https://www.cocos.com/">https://www.cocos.com/</a>

video game technology, which refers to the core components of some compiled editable computer game systems or some real-time interactive image applications. The emergence of the game engine reduces the difficulty for game designers and developers so that they do not need to start from the most basic code. The development of game engines drives development in the Metaverse and provides users with an experience that is closer to the real world. Current representative game engines are listed in Table VI.

#### IV. METAVERSE: THE SOCIALITY PERSPECTIVE

The advent of the Metaverse will transform traditional social networks into interactive and immersive 3-D virtual social worlds. The Metaverse will be a global community and allow people from all over the world to connect and interact with each other in a way that has never been possible before.

##### A. Virtual Social Worlds

The convergence of social networks and VR has enabled the creation of virtual social worlds. These are immersive 3-D environments that extend the traditional content-oriented social networks into a fully interactive social simulation. In a virtual social world, users are represented by avatars that navigate through the virtual world and interact socially with other users. Users can teleport through different virtual social worlds, participate in events, and even conduct currency transactions. Virtual social worlds are complex social systems that integrate the real social space with the virtual social environment through the universal design of cyber–physical–social systems (CPSSs) [54].

Fig. 5 shows the enabling technologies that have contributed to the development of social Metaverse applications. The integration of physical and social space with the virtual social space requires the continuous mapping of social interactions and social events in the virtual social world. The virtual social world must meet the four design requirements.

- 1) *Realism*: The requirement for users to sense emotions while immersed in the virtual social world.
- 2) *Ubiquity*: The requirement that the virtual social Metaverse is ubiquitously accessible from various devices and locations. The user's virtual identities or cyber persona remain connected during transitions within the virtual social world.
- 3) *Interoperability*: The ability of the virtual social world to employ standards that allow users to teleport/move seamlessly between different virtual locations in the Metaverse without disruption or interruption of their immersive experience.
- 4) *Scalability*: The ability of the virtual social world to manage computational power so that a large number of users can interact socially in the Metaverse without disruption or interruption of their immersive experience [1].

##### B. Social Privacy in the Metaverse

The digital traces of users in the social Metaverse can be tracked to reveal the true identity of the user, as well as other sensitive information, such as location, shopping preferences, and even financial details [55]. Privacy plays a crucial role in building the social Metaverse. In traditional social networks, privacy protection schemes are relatively easy to apply because users can decide with whom they want to share their social media content. In contrast, the existing privacy controls may

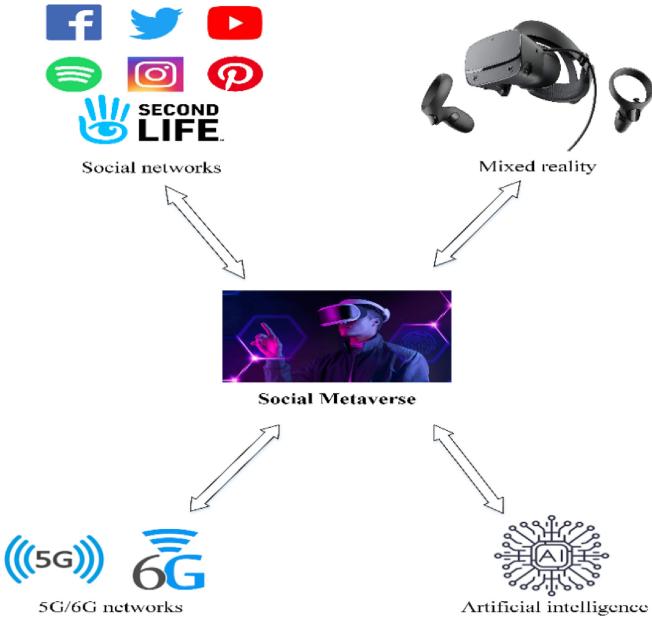


Fig. 5. Four enabling technologies for the interactive social Metaverse.

not be applicable to the social Metaverse, which makes the problem of protecting users' privacy more challenging [56]. Consider the following example: If a user browses for goods and makes purchases in the Metaverse, an avatar tracks his/her avatar and records what he/she bought and his/her travel history, this information can be used to violate privacy in the real world.

One of the proposed solutions to the privacy issue of the social Metaverse is social cloning [47], which involves creating multiple clones for each user in Metaverse to confuse attackers attempting to track individuals in Metaverse. Such a privacy scheme may solve some problems, but it will also bring new problems, such as managing multiple user identities.

Other privacy protection schemes include disguising users by periodically changing the appearance of the avatar to make it harder for attackers to target specific individuals and making the avatar temporarily invisible when being tracked [57]. A privacy framework for the social Metaverse can combine multiple privacy schemes, with the user choosing to enable a particular privacy option for each situation. Falchuk et al. [47] proposed a privacy scheme that combines various privacy techniques, such as virtual cloning, private copy, mannequin, avatar lockout, avatar disguise, teleport, and invisibility, as shown in Table VII. At the same time, other researchers argue that the private jurisdiction of the user's country should also apply in the Metaverse, especially for social relationships in the Metaverse. Lo [58] has argued that Canada's Personal Information Protection and Electronic Documents Act (PIPEDA) should be the governing privacy law in virtual social networks such as Second Life.

## V. METAVERSE: THE HYPER-SPATIO-TEMPORALITY PERSPECTIVE

In the real world, human behavior occurs in the time and space of the physical world. While spatio-temporality

TABLE VII  
PRIVACY-PRESERVING SCHEMES IN THE SOCIAL METAVERSE

Privacy Scheme	Description
Avatar cloning	Create multiple avatar clones that look identical to confuse privacy intruders.
Disguise	Allow users to switch between multiple disguised avatars.
Mannequin	Replace the avatar with a robot that mimics the user's behavior, and transfer the user to another location if tracking is suspected.
Invisibility	Allow the avatar to become temporarily invisible to prevent tracking by privacy intruders or bots.
Teleport	The ability for the avatar to instantly teleport to other locations in the Metaverse.
Private worlds	Allows users to designate specific locations in the Metaverse as private locations.
Lockout	Temporarily locks certain parts of the Metaverse for private use by specific avatars.

ensures that human behavior proceeds normally, it also limits human behavior from deviating from its norms. The concept of hyper-spatio-temporality has been mentioned and introduced in Chinese mythology, Taoism, and some Western philosophical theories. Human imagination and exploration of virtual worlds have led to the gradual conceptualization of hyper-spatio-temporality. Dionisio et al. [1] described the development of virtual worlds from early literary works and text-based games to 2-D graphical interfaces and now to 3-D graphical interfaces.

The Metaverse is the latest stage in the development of 3-D virtual worlds, providing users with open, interactive, multi-sensory, and highly immersive environments in which they can create content. The Metaverse breaks the constraints of time and space in the real world. The hyper-spatio-temporality of the Metaverse is reflected in the fact that the Metaverse has a different time and space from the real world. It does not stop at building a static digital space but a virtual space that evolves in parallel with the real dynamic world. The Metaverse opens up a new habitat for humanity and brings a different experience to users.

Hyper-spatio-temporality enables users to move and interact in a highly realistic 3-D virtual space, experiencing a sense of presence and immersion that is indistinguishable from the physical world. In the Metaverse, users can interact in real time with digital objects and environments, creating an experience that simulates the physical world more accurately and realistically than ever before. The Metaverse provides a fully immersive and interactive digital world that allows users to explore virtual space with unprecedented freedom and interact with dynamic and evolving digital objects and environments, creating a sense of continuous and dynamic activity that is not limited by the physical world. Through advanced haptic feedback and other sensory technologies, users can experience a heightened sense of presence and embodiment in the virtual world, making it almost indistinguishable from the physical world.

Hyper-spatio-temporality also involves the ability to experience time and space in different ways, as the virtual environments constructed by the Metaverse can exist and evolve independently of the physical world. In the Metaverse, people can interact with each other, conduct business, and engage in entertainment activities in a virtual environment that is not limited by the time and space constraints in the physical world. The Metaverse breaks through the limitations of time and space in the real world, creating a virtual world that is not governed by the physical laws of the physical world, fundamentally changing the way people interact with each other and experience the world around them. In the Metaverse, users can instantly travel to any location in the virtual world, regardless of their physical location in the real world. Users can also communicate with others in real time, regardless of their geographic location. Additionally, the Metaverse can achieve hyper-spatio-temporality by allowing people to experience time and space in impossible ways in the physical world. In the Metaverse, people can manipulate time and space to create new experiences, such as slowing down time, speeding up time, or moving through space in ways that are impossible in the physical world. For example, users can explore virtual fantasy worlds that cannot be reproduced in the physical world, or participate in events and meetings held in virtual space, breaking down geographic barriers and saving time and resources.

With its advanced AI and machine learning technologies, the Metaverse is in a stable state of development and demonstrating infinite possibilities for exploration and discovery. It can be said that the Metaverse has opened a new era for human experience, in which the boundaries of the physical world are surpassed, and a new world of infinite possibilities is open to all who are willing to explore it. In the future, it will be integrated into people's daily lives and widely applied in various fields, and detailed application areas are listed in Table VIII. Additionally, despite the hyper-spatio-temporality of the Metaverse, engineers should maintain consistency of user interaction in space and time to avoid causing confusion in users' spatio-temporal perception.

## VI. OPEN ISSUES

### A. Interaction Issue

Interactive technologies are used to create immersive and interactive virtual environments in the Metaverse, providing users with a seamless and intuitive way to interact with the virtual world, objects, and other users. In general, the interactive technologies in the Metaverse need to meet the following requirements.

- 1) Interactive devices should be lightweight, easy to use, wearable, and portable.
- 2) Interactive media should be transparent, allowing users to ignore the traces of technology and better immerse themselves in the virtual world.

Common interactive technologies include somatosensory technology, XR technology, and BCIs.

The somatosensory technology refers to using sensors and devices to detect and transmit information about users' body

movements, touch, and other bodily sensations in the virtual environment. One of the current problems with the somatosensory technology is its accuracy. Although devices can detect a wide range of movements and sensations, they may not be able to capture subtle or complex movements or sensations. This will reduce immersion in the Metaverse, as users may not be able to fully express themselves or interact with the virtual environment as they would in the real world. Another challenge is the cost and accessibility of the somatosensory technology. High-quality somatosensory devices can be expensive, which can limit their availability. In addition, some users may have physical limitations that prevent them from using certain somatosensory devices and fully participating in the Metaverse.

The XR technology, including VR, AR, and MR, is a vital component of the Metaverse that allows users to fully immerse themselves in a digital environment and interact with virtual objects and other users. However, the XR technology is still in its early stages and faces many limitations that could hinder its ability to realize the Metaverse's potential fully. One significant limitation is the lack of widespread adoption of the XR technology, primarily due to high hardware costs, limited accessibility, and the need for specialized knowledge to create and operate XR applications. Another limitation of the XR technology is that although it can provide a relatively immersive experience, its level of sensory input is still limited.

The BCI technology is another interactive technology that allows users to control devices using brain signals. One key limitation of the current BCI technology is the lack of accuracy and precision in interpreting brain signals. The human brain is an incredibly complex and dynamic system, and interpreting the signals it produces is a difficult task. Although BCIs can detect certain brain signals and use them to control simple devices, they often have difficulty accurately distinguishing between different thoughts and emotions, resulting in misinterpretations.

The BCI technology can be divided into three types: 1) invasive; 2) semi-invasive; and 3) noninvasive. Invasive BCIs involve the surgical implantation of electrodes into the brain cortex, which provides highly accurate signal recordings but also carries high surgical risks and tissue rejection. Semi-invasive BCIs involve implanting electrodes into the cranial cavity but outside the cerebral cortex, while noninvasive BCIs rely on brain signals interpreted through wearable devices attached to the scalp. Noninvasive methods avoid the safety risks associated with complex surgeries but have lower accuracy.

Addressing this challenge will require continued advancements in the above technologies, such as developing lighter devices to ensure transparency and reducing device costs for widespread adoption. Alternatively, new technologies can be developed to improve the interaction of the Metaverse.

### B. Computing Issue

Computational power refers to the ability of a computer system to process large amounts of data and perform complex calculations efficiently. The limitations of computational

**TABLE VIII**  
APPLICATION AREAS OF THE METAVERSE

Area	Description
Smart City	<p>The complexity of urban management is increasing. New approaches to urban management are needed to better coordinate and manage the city's resources [59]. As a virtual world parallel to reality, the Metaverse uses digital twins as an underlying support technology, which is also essential for building smart cities.</p> <p>Digital twin technology can digitally map the physical world, fully capture urban data such as people, vehicles, objects, and space, and form a visible, controllable, and manageable digital twin city. It can improve the efficiency of resource utilization, optimize urban management and services (e.g., traffic management and environmental protection [60]), and improve the quality of life of citizens.</p>
Game Industry	<p>The Metaverse is closely related to the gaming industry, and it is likely that it will first be presented in the form of a game.</p> <p>The rich interactive methods and scene rendering technology in games can provide players with a more immersive and interactive experience, thereby increasing player engagement and enriching the user experience in the Metaverse [61].</p> <p>At the same time, the Metaverse can create new forms of game design and development, enabling game developers to create more complex and rich game environments and gameplay.</p>
Remote Work	<p>Due to the impact of the epidemic, the importance of remote work and virtual meetings has become increasingly evident. The Metaverse can overcome the limitations of traditional remote work models, further enhancing their functionality and providing a more immersive, collaborative, and productive work environment, thus creating more opportunities for remote work.</p> <p>By providing a more immersive and interactive environment, remote workers can collaborate and communicate more effectively. Additionally, the Metaverse can effectively reduce physical distractions such as noise, allowing workers to focus more on their tasks, thereby improving work efficiency and productivity.</p>
Travel and Tourism	<p>The Metaverse provides new forms of tourism, enabling digital travel and digital exhibitions. Users can visit and tour attractions and participate in virtual activities without leaving their homes, obtaining immersive experiences. Compared to physical travel, this method is more convenient and affordable. Additionally, The Metaverse provides a platform for promoting tourist attractions, attracting users to visit in person, thus effectively promoting the development of the tourism industry.</p>
Education	<p>The Metaverse has the potential to contribute to education in several ways:</p> <p>Firstly, the Metaverse can provide students with more immersive and interactive learning experiences. By constructing virtual scenes, students can have experiences that are close to reality. While avoiding risks and reducing costs, this helps students learn complex concepts and knowledge.</p> <p>Secondly, the Metaverse can provide a wider range of learning resources, lowering the threshold for education. Anyone can access a large number of educational resources through the Metaverse.</p> <p>Finally, the Metaverse can provide personalized learning. By monitoring and evaluating students' learning processes, the most suitable learning plan can be developed.</p>
Economy	<p>The Metaverse enables the creation of a virtual economy within a virtual world. In this virtual economy, people can trade virtual assets such as virtual real estate, digital art, and virtual currency. However, the virtual economy will be different from the real-world economy, and therefore may require a specialized regulatory framework to ensure stability and fairness.</p> <p>The Metaverse can also create new employment opportunities and industries. For example, blockchain and decentralized systems can enable new economic models in the Metaverse, such as decentralized markets, virtual currencies, and smart contracts. This can promote a more dynamic and diverse economic ecosystem composed of creators, consumers, and entrepreneurs in the Metaverse, creating new opportunities for software developers, game designers, content creators, and others.</p>
Culture and Entertainment	<p>The Metaverse has the ability to create new forms of media, cultural expressions, and modes of cultural creation, providing creators with new platforms and enabling users to experience content in new ways. For example, it can provide immersive movies, offering audiences a more immersive and interactive experience.</p> <p>In addition, the interactivity and immersive nature of the Metaverse can promote the development of entertainment activities such as virtual concerts, virtual sports events, and virtual theatrical performances.</p>
Social	<p>The social aspect of the Metaverse can integrate the advantages of both online and offline social interaction. By breaking through the constraints of time and space, it can provide diverse forms of social interaction while also using technologies such as holographic virtual images to create immersive scenes and bring users a close-to-real experience.</p>

power pose significant challenges to the development of the Metaverse. In the context of the Metaverse, computational power is a critical support for creating immersive environments and enabling real-time interaction between users. The Metaverse requires rendering complex 3-D scenes, processing large amounts of data from multiple sources, and supporting a large number of concurrent users. As a result, its computational requirements are enormous, and current computing

power may not be sufficient to support the full implementation of the Metaverse.

Therefore, the development of the Metaverse will require significant investments in hardware, software, and infrastructure, including the development of high-performance graphics cards, processors, and networking technologies that can support the demands of the Metaverse. In addition, it is necessary to develop more efficient algorithms and programming

techniques to optimize the use of available computational power.

### C. Ethical and Moral Issues

As the Metaverse develops, the scenes from science fiction movies may no longer be a matter of imagination when the consciousness of the brain can be edited, stored, and replicated like computer information. This is where ethics becomes crucial. The existing moral principles are no longer applicable, and the formulation of new ethical standards often lags behind the development of the Metaverse. Therefore, regulation of the Metaverse should be strengthened, and relevant laws should be developed and updated promptly. The Metaverse gives people new identities and creates a new and free space for life and work. It includes more complex social relationships. As the next generation of the Internet, the Metaverse must control and restrain user behavior, establish clear ethical and moral standards, and maintain a good and orderly ecological environment for the Metaverse. The ethical and moral issues of the Metaverse include the following.

- 1) The Metaverse may blur the boundaries between the real world and the virtual world, raising concerns about the authenticity of digital identities and the possibility of identity theft.
- 2) The Metaverse may challenge intellectual property rights, including copyright and trademark infringement.
- 3) The Metaverse may exclude those who cannot obtain the necessary technology or lack the skills to use it, thus exacerbating existing social and economic inequalities.
- 4) The Metaverse may require new forms of governance and regulation to ensure that it operates fairly and transparently without becoming a tool for abuse or exploitation.
- 5) The Metaverse may have significant impacts on culture and society, raising questions about the values and norms it advocates and how it shapes social interaction and relationships.

To address these ethical and moral issues, it is first necessary to establish clear policies and guidelines to ensure transparency in the operation and decision-making process of the Metaverse. Second, relevant laws need to be made to regulate behavior. Finally, it is significant to develop relevant technologies to improve the security of the Metaverse and continuously explore new solutions.

### D. Privacy Issue

The Metaverse is closely connected to the real world and corresponds to users' identities. Key technologies used in the Metaverse, such as the IoT and blockchain, pose certain security and privacy risks that need to be addressed [62], [63]. The Metaverse is a virtual world where people can interact with each other, participate in activities, and engage in transactions. As the Metaverse develops, it will collect a large amount of user personal information, including preferences, behaviors, and communication patterns. Therefore, developers must implement strong privacy and security protocols to protect users' personal information from unauthorized access or

misuse by others. This involves using a series of necessary security measures to protect user data and implementing strict data access controls to ensure that only authorized personnel can access user data. In addition, as the construction of the new generation network, the Metaverse, like previous network environments, must establish relevant laws and regulations for data privacy and security in the Metaverse. These laws need to be flexible and adaptable to keep pace with the rapid changes in the development of the Metaverse.

### E. Cyber-Syndrome

Cyber-Syndrome is a physical, social, and psychological disorder caused by excessive Internet use [64], [65]. With the constant development of interactive methods, electronic devices have become smaller and more portable. The simplification of devices has led to people spending more and more time on the Internet. With the development of the Metaverse, the high immersion and interactivity it provides will lead to people investing more time and energy in virtual environments, exacerbating the problem of Cyber-Syndrome.

Physically, excessive Internet use can lead to a sedentary lifestyle, which can cause various health problems, such as obesity, poor posture, and eye strain. Spending extended periods in virtual environments can also cause motion sickness and dizziness. In terms of social interaction, spending too much time in virtual environments can lead to social isolation, exacerbating mental health problems, such as depression and anxiety. It can also lead to detachment from reality and a lack of interpersonal skills, making it difficult for individuals to adapt to the real world. Psychologically, excessive Internet use can lead to addiction, causing individuals to prioritize their virtual lives over their real lives. This can result in decreased productivity and a deterioration of mental health and overall well-being.

Therefore, as the Metaverse continues to develop and become more widespread, it is necessary to address the potential risks associated with the excessive use of virtual environments. More in-depth and comprehensive research and analysis are needed on this topic to address the issue of Cyber-Syndrome. In addition, it is also necessary to develop reasonable guidance plans for users and implement relevant regulations for regulation.

### F. Compatibility and Standardization

As a virtual world closely connected to reality and with multidimensional properties, it is necessary to consider compatibility and standardization issues of the Metaverse to ensure its seamless operation. This includes compatibility issues between the Metaverses created by different companies, as well as compatibility between the Metaverse and the real world.

Compatibility issues are related to ensuring effective communication and collaboration among different components and systems within the Metaverse, allowing all participants in the Metaverse to adopt and adhere to universal protocols and standards to ensure interoperability. On the other hand, standardization is related to the need for developing universal specifications and frameworks. Standardization specifications

and frameworks can ensure the uniformity and consistency of the entire Metaverse, including defining standards for content creation, distribution, and consumption, as well as ensuring a governance framework for fairness, transparency, and accountability in the Metaverse. In addition, as the Metaverse is a vast and complex virtual world, there will be challenges in ensuring that these standards and protocols can be extended and adapted to meet the changing needs of the Metaverse. Therefore, as the Metaverse evolves, it is essential to establish a continuous process for monitoring and updating these standards and protocols.

## VII. CONCLUSION

The Metaverse, a concept still in development, has wide-ranging development and application prospects. This article first introduced the policies, representative companies, and typical products of various countries and international organizations related to the Metaverse. The statistics of Metaverse-related publications in the Web of Science database and SCOPUS database were combined to analyze the development history, current situation, and relationship between each country's Metaverse policy and its corporate design. Second, the technical framework of the Metaverse is summarized from the perspective of multitechnology convergence. The framework includes five aspects: 1) communication and computing infrastructure; 2) management technology; 3) fundamental common technology; 4) VR object connectivity; and 5) VR space convergence. Third, the sociality of the Metaverse is introduced, that is, the emergence of the Metaverse transforms the traditional social network into an interactive and immersive 3-D virtual world. Fourth, the Metaverse is introduced from the perspective of hyper-spatio-temporality, and the application areas of the Metaverse are summarized. Fifth, open issues of the Metaverse are discussed.

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