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Review Article

From Three-Body game to metaverse

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ABSTRACT

This paper aims to study the concept of the metaverse as reflected in the Three-Body game in the TV series *The Three-Body Problem*, as well as the current development status of the metaverse in the real world. Firstly, the Three-Body game in *The Three-Body problem* is analyzed and explained to uncover the underlying metaverse knowledge. Then, through a literature review, the implementation and application scenarios of the metaverse in various industries are investigated from the databases Web of Science and Scopus, using keywords such as "metaverse", "Three-Body", "virtual world", "virtual reality games", and "human-computer interaction". Nearly 10,000 relevant articles were retrieved, and 20 articles were selected for in-depth qualitative and quantitative analysis. Subsequently, the content of the literature is summarized from three aspects: the current development status of the metaverse, advancements in virtual reality technology, and advancements in human-computer interaction technology. The application status and technological progress of the metaverse in various industries and the existing technological limitations are discussed. By extending the concept of the metaverse from science fiction, this paper provides research ideas for the future development of the metaverse.

Keywords: the *Three-Body Problem*; Three-Body game; metaverse; human-computer interaction; virtual reality

1. Introduction

A few years ago, Liu Cixin, a science fiction writer, conceived the concept of the "metaverse" in his *The Three-Body Problem* series of works[1]. With the rising popularity of the concept of the "metaverse", people once again focus on this groundbreaking domestic science fiction work, *The Three-Body Problem*[2–4]. In the world of *The Three-Body Problem*, humans on Earth struggle to survive against the technologically advanced Trisolarans, who are located four light-years away. Earth's civilization is pushed to the brink and is forced to take extreme measures to mutually destroy each other. This work depicts an imaginary world, a broad concept of the metaverse[5–7]. The survival and development of civilizations require vast resources, and conflicts arise among civilizations as they compete for resources, resulting in fierce interstellar wars. In each independent metaverse, there are unique settings and narratives[8]. Science fiction works are based on boundless scientific imagination and do not necessarily have to be grounded in scientific principles; their content can be completely unscientific[9]. Therefore, science fiction works may contain fantastical elements, such as describing how a magician uses magic to observe and analyze technological products like airplanes. However, the author's understanding of characters, societies, civilizations, and

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species in the work is limited by specific historical backgrounds and scientific levels. The metaverse, however, is a virtual space constructed using scientific technology existing in people's imaginations[10-12].

Another aspect contributing to their shared development is the high degree of congruence between the core technologies and foundational support of the science fiction industry and those of the metaverse. Communication computational power and blockchain technology are essential to the success of the metaverse, which uses virtual reality (VR), digital twins (DTs), and immersive interaction to unite the real and virtual worlds[13,14]. Specifically, the metaverse of the Three-Body is remarkably similar to the metaverse now being investigated and implemented[15–17]. The idea of a "metaverse", first introduced in the novel Snow Crash, has become more popular worldwide due to technological advancements and the growth of the science fiction industry[18]. The scientific fiction industrial chain, which consists mostly of science fiction films, TV series, games, and immersive entertainment, is a typical application and scenario of the metaverse[19–21]. Therefore, hastening the shift from cultural industry to the digital economy and facilitating the upgrade and iteration of building metaverse cities can be achieved by encouraging the integration and development of science fiction and the metaverse[22, 23]. As such, it is practically relevant to inquire into the current state of study into the metaverse as a result of The *Three-Body Problem* simulation.

This paper analyzes the scenarios and technologies contained in the game, starting from the Three-Body game in The *Three-Body Problem*. The terms "metaverse", "Three-Body", "virtual world", "virtual reality game", and "human-computer interaction" were used to locate approximately 10,000 relevant publications in the literature databases Web of Science and Scopus. Twenty substantive research results were selected for in-depth reading to delve deeper into the mysteries of the metaverse. These results were chosen after we eliminated studies with conflicting or ambiguous findings, those without replication, and those that were too broad in scope or had the same title. Some of these publications were also read with the help of the Google Scholar platform to give a reference for the future development of the metaverse by summarizing the present state of research on the topic in widely studied areas like gaming and entertainment.

2. The metaverse in the *Three-Body Problem*

The Three-Body Problem, a popular new TV series in China, has captured the attention of many sci-fi readers and viewers[24,25]. In the TV series, the Three-Body organization develops a game called "The Three-Body" with the aim of helping Earthlings understand the Three-Body world[26]. Since the game's Three-Body star systems digitally mirror the real-world orbits of those stars, it clearly fits the metaverse criteria[27–29]. In addition to being a crowdsourced game, this Three-Body game lets users investigate the secrets of the sun's motion in the Three-Body metaverse on their own or with others[30]. The game provides players with a metaverse to verify the Three-Body Theory, which is the theory of the motion of the three suns. The motion trajectories of the three suns in the game should be read from the historical records of the Three-Body world rather than generated through formulas. If there were already formulaic patterns, then the Three-Body game would not need to verify the patterns of the three suns[31–33]. In addition, the TV series also indicates that the Three-Body world has no regularities, so the plot of the Three-Body game can only be generated from historical records. **Figure 1** illustrates some of the game visuals shown in the TV series.

Figure 1 shows some game visuals from the TV series The *Three-Body Problem*. It can be observed that entering the Three-Body game requires auxiliary equipment, similar to the familiar VR/augmented reality (AR) game equipment used today. The user enters the game and automatically shifts into immersion mode, similar to the soul travel to the game. It might be seen as a way for players to experience VR, where their emotions are reflected in their physical form. In The *Three-Body Problem*, the celestial motion patterns are verified through representative technologies from different stages of human history. Each failed verification results in the downfall of a civilization. Eventually, mathematicians deduce that the Three-Body Theory has also failed through evolutionary computation, further confirming the chaotic nature of the Three-Body world. It is clear that even the most basic mystically based predictions do not necessitate the adoption of metaverse technology when seen through the lens of the validation capabilities of the Three-Body game for modeling the Three-Body Theory. Yet, there are more obstacles to overcome when putting Mozi's mechanical predictions into practice in the metaverse because of the unique modeling challenges posed by the metaverse's operational environment.

Figure 1. The Three-Body game scene in *The Three-Body Problem* (a. game background; b. Three-Body metaverse; c. humans enter the game screen; d. the role of humans in the game).

In addition, when the timeline of The *Three-Body Problem* reached the Qin Dynasty, von Neumann asked Qin Shihuang to borrow 30 million warriors to build a "computer". Each individual picks up two balls, one red and one white, to represent the binary principle of 1, 0. According to this rule, the 30 million army constitutes the central processing unit, memory, external memory, and bus. The human "computer" composed of Qin Shihuang's 30 million armies is undoubtedly the most difficult. It is equivalent to forming a computer in the metaverse, that is, simulating a computer from the bottom. The pace of progress in many human endeavors would be considerably accelerated if a metaverse existed that could replicate computer architecture. The TV series suggests that the Three-Body game is a digital duplicate of our own reality since the human "computer" in the game truly occurred in the Three-Body World. The inventiveness of the author is on full display in all these story devices. Still, they also force us to reevaluate the path of our metaverse's future evolution and point the way toward new avenues of inquiry that could one day lead to its physical embodiment.

The game envisioned by Liu Cixin in his novel The *Three-Body Problem* is now the domain of professional game designers[34,35]. Initially, this novel gained popularity among a relative niche group of science fiction literature enthusiasts, but later it gradually grew into a major intellectual property, with adaptations into various forms such as animation, radio drama, and movies, as shown in **Table 1**.

Table 1. Adaptations of *The Three-Body Problem* (incomplete statistics)

Years	Type	Director/Producer	
2014	Movie	*The Three-Body Problem I*	Zhang Fanfan
2015	Animation	*Waterdrop - Three Body II: Dark Forest*	Wang Ren
2015	Fan-made animation	*My Three-Body Problem*	Li Zhenyi
2016/2019	Stage show	*Three-Body problem*, *Three-Body Problem II: Dark Forest*	Lotus Lee Future Drama Studio
2019	Radio drama	*The Three-Body Problem*	Himalayas
2021	Animation	*The Three-Body Problem*	Station B, Three-Body Universe, Art and Painting Kaitian
2021	TV drama	*The Three-Body Problem*	Tencent Video
2021	TV drama	*The Three-Body Problem*	Netflix

3. Application progress of the metaverse

3.1. Connotation and development history of metaverses

Science fiction writer Neal Stephenson of the United States used the term “metaverse” in his 1992 novel *Snow Crash*[36,37]. The concept of the metaverse is a science fiction hypothesis about the future of humanity and was translated as “超元域” when the novel was introduced in China[38]. As a result of this hypothetical setting in science fiction, many have taken an interest in learning more about the metaverse and envisioning its potential realization through technical methods. The term “metaverse” is no longer restricted to the confines of cyberpunk fiction’s cyberspace[39,40]. The convergence of metaverse and real-world economies is made possible by advancements in blockchain technology and non-fungible tokens (NFTs)[41]. For example, players who are skilled at playing games in science fiction novels may not be well-known in real life, just like the character settings in “Ready Player One”. Nonetheless, these players can amass sufficient riches through NFTs gained in games and even alter their financial standing in the real world.

The term “metaverse” has not yet been given a definitive, standardized definition. According to Baidu, it is defined as “a virtual world that is linked and created through technological means, mapped and interacted with the real world, and possesses a new type of social system in the digital living space” [42]. Wikipedia defines the metaverse as “a communal virtual shared space formed by the merger of augmented physical reality and virtual space”[43]. The definitions of “mate” and “verse” on Baidu and Wikipedia, respectively, make it clear that both terms have the same meaning: “beyond” and the “space” built in the “digital space”[44]. Therefore, from a translation perspective, “mateverse” does not necessarily imply “universe” or “cosmos” in the traditional sense, but from the perspective of the “transcendence” and “transformation” reflected in the digital world it creates, it is indeed a new form of the spatial domain[45]. In addition, it is more widely accepted by society due to the fact that the term “metaverse” easily triggers interest in the industry, has a sense of science fiction, and has strong communication effects. **Figure 2** depicts the ecological architecture of the metaverse.

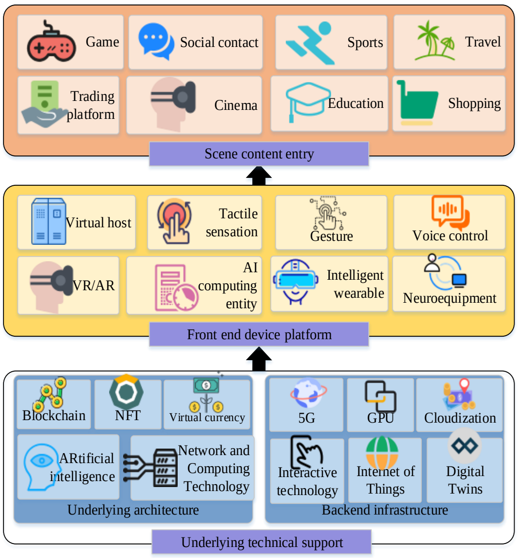

Figure 2. Example of the metaverse ecological structure.

From a technical point of view, the metaverse can be viewed as an amalgamation of several technologies. Immersive experiences, efficient and convenient procedures, spatial mapping of digital items, empowered freedom for editing, secure and dependable transactions, etc., are only some of its many notable qualities[46]. In terms of individual technology, VR technology tries to move the real world into virtual space; AR technology tries to put the virtual world into reality; DTs technology tries to copy all the physical existence of the real world; Internet and the Internet of Things (IoT) technology tries to closely connect people with people, people with things, and things with things. The goals of cloud computing, artificial intelligence (AI), and fifth-generation (5G) wireless technologies are as follows: (1) global integration of dispersed computer resources; (2) machine learning and cognition on par with humans; (3) high-speed, low-latency data transfer. Blockchain technology guarantees the safety of digital assets due to its immutability and privacy properties. The foundation of “metaverse” technology is laid by combining these technologies. **Figure 3** compares the structure of the metaverse with that of the

International Organization for Standardization (ISO).

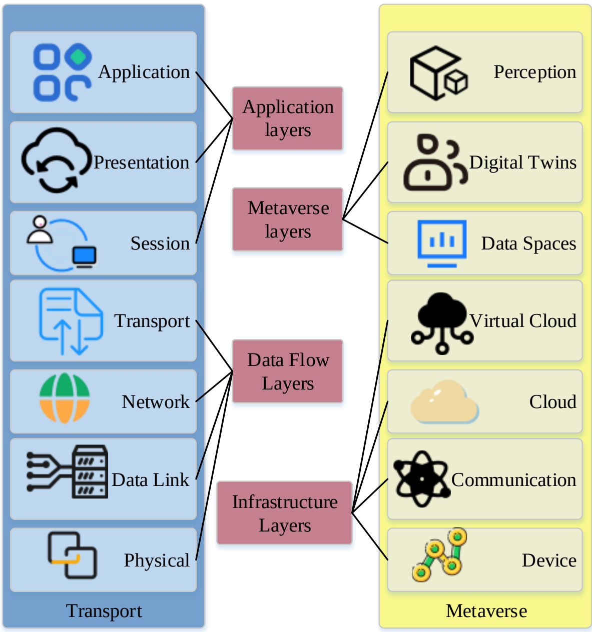

Figure 3. Metaverse vs. seven ISO layers.

The device layer, the communication layer, the cloud layer, the virtual cloud layer, the data space layer, the DTs layer, and the perception layer are only a few of the layers that make up the metaverse. To store actual data and software, many system integrators employ virtualized cloud services, such as those offered by Amazon Web Services and Google Cloud Platform. Implementing an open data framework relies heavily on the data space layer, which defines the metaverse's ontology. The DTs layer ensures the personalized and unique aspects of the metaverse, creating individual experiences. The perception layer will provide a setting in which a number of services can be seamlessly integrated into the landscape.

The creators and users of the metaverse require a certain level of technical know-how, a high degree of imagination, creativity, and the use of human subjectivity and initiative. On the one hand, the metaverse's logical integration of science and technology represents the crystallization of human subjectivity in the form of technological progress and awareness advancement. On the other hand, human subjective initiative is also required for the ongoing enhancement and evolution of the metaverse's technological content. The items in the metaverse are based on things that are used in human activity in the actual world. Although the metaverse creates a virtual space in form, ultimately, virtual space is still an extension of the human world and remains within the scope of the human world.

3.2. Application status of the metaverse in various industries

The metaverse is actually the integration of the digital world and the physical world, digital life and social life, digital assets and physical assets, digital economy, and the real economy, as well as digital identity and real identity[47]. The key to the development of the metaverse is integration, and it is not just a virtual space. The metaverse, a potentially limitless future notion, is already being used in a wide range of fields, from gaming and manufacturing to retail and education to live entertainment and tourism.

Games

Essentially, the digital realm of the metaverse can be viewed as the progenitor of open-world games[48]. In the past decade, massive open-world games have emerged as a key trend in the evolution of the digital entertainment sector. These games allow players to find their own unique style of play because of features like branching storylines, open worlds, and non-player actors with high levels of intelligence. The metaverse brings a sense of reality from real life into the game, where virtual game items and currency are real-world assets. Tokens in the game's economy provide players the freedom to build their own regions and can even be used to alter the game's mode and future development. For example, a pet trading and battling game called Axie Infinity on the Ethereum blockchain has introduced a "Play-to-Earn" model, allowing rural residents in the Philippines to earn money in the game and help many unemployed individuals during the pandemic[49,50]. The core of Axie Infinity is the "Axies", which are pets with various body parts to choose from, including aquatic, beast, plant, and reptile parts, each with different rarity levels such as common, rare, super rare, and legendary[51]. Axies can be composed of different combinations of body parts, making them highly variable and usually very rare[52].

Decentraland is a 3D VR platform where land can be owned as virtual assets and freely developed by owners, including real-life buildings such as casinos, financial centers, and shopping centers[53]. Roblox is a large platform that supports multiplayer online game creation, where users can freely create games according to their personal preferences, design their own items, and create different types of games[54–56]. However, the development of metaverse games is not as simple as imagined. Video game production often involves using automation technology to generate content, bind animations, set map lighting, and script behaviors. Automation of programming and artistic functions is increasingly integrated into game engines, in combination with other software applications in the 3D production ecosystem, laying the foundation for platform companies to position themselves as future metaverse. The research by Chia discusses the automation of metaverse game engines as platform tools for designing and simulating interactive 3D worlds inside and outside of games, highlighting the impact of engines on game creators and game research, covering multiple fields such as game development, entertainment media, architecture, engineering, construction, and manufacturing[57]. The aforementioned games all showcase the powerful imaginative scenes that humans can achieve in the metaverse.

Industrial manufacturing

The Industrial Metaverse is an industrial ecosystem that deeply integrates new information and communication technologies, such as extended reality (XR) and DTs, with the physical industrial economy[58]. In an interview, NVIDIA's Chief Executive Officer claimed that using the metaverse would help businesses cut costs and boost efficiency[59]. The metaverse production workshop enhances the accuracy and speed of factory design and production achieves the goals of cost savings and efficiency improvement. Enterprises can simulate factory production processes, plant growth, and even simulate real-world power grid operations in the metaverse, thereby reducing waste of raw materials and gaining economic benefits. Among them, Omniverse is an open metaverse platform developed by NVIDIA, designed specifically for virtual collaboration and realistic real-time simulation. The platform's virtual factory integrates planning data and applications for the entire process while also providing real-time collaboration and strong compatibility[60].

Omniverse is an open metaverse platform that allows for the simultaneous creation of content by several users, allowing them to build and simulate content that follows the rules of physics in a shared, virtual 3D world that is highly similar to the actual world[61]. This platform is seeing increasing use in the manufacturing sector, with examples including the port industry. It has the potential to drive real-time operations in a dynamic, data-driven fashion and encompasses the full cycle of cargo handling, port operations, storage, and shipping[62]. A 5G environment can also fully simulate people, vehicles, objects, regulations, and the environment in a port's industrial equipment situation. For instance, BMW used Omniverse to construct digital plants in which engineers, designers, and experts from all over the world may work together in the same environment to perform intricate activities like product planning, design, and simulation.

Remote office/video conferencing

Due to the spread of the Corona Virus Disease 2019 (COVID-19) pandemic, theater and performing artists need to find creative and safe solutions to continue their work. Online video conferencing tools and VR platforms seem to be promising opportunities for exploring new ways to connect art with audiences[63]. At the same time, traditional remote work also faces some challenges, such as a lack of real-time interaction and low communication efficiency. Metaverse, on the other hand, offers virtual office spaces that provide a "face-to-face" manner of working, which has garnered significant interest. For example, Google has introduced the "Project Starline" initiative, aiming to visualize remote interactions three-dimensionally, allowing participants to observe chat partners from different angles and engage in physical or eye contact communication[64]. Facebook has also launched Horizon Workrooms, a remote collaboration tool that enables colleagues wearing VR devices to communicate face-to-face in the same virtual meeting room, breaking down the barriers of screens[65].

Shopping

Technologies such as VR, AR, and digital simulation are helping to reshape the landscape of online e-commerce, and the application of metaverse in the retail sector is also foreseeable[65]. In the metaverse, the creation of shopping centers and the simple operation of one-click ordering allow consumers to complete shopping and consumption in a game-like experience. Furthermore, the metaverse has the potential to break free from the form and functionality of physical stores, injecting more imagination into the digital shopping experience. The immersive technology of the metaverse provides a better space and medium for the retail e-commerce scene, constantly upgrading the consumer experience. For example, Gucci has partnered with Roblox to launch a virtual exhibition called “The Gucci Garden Experience”, where players can appreciate and purchase virtual items[66]. Tmall has also introduced a 3D version of Tmall Home Decoration City, providing consumers with a 360° display of furniture and home decoration effects to help users browse different styles of decoration designs and make decisions[67]. In addition, online retail platforms may deploy various metaverse virtual showrooms to facilitate consumers’ understanding of products. For instance, Zhang et al. developed a game theory model to study the strategic interaction between intermediaries and third-party sellers when deploying virtual showrooms. The results showed that both cost-specific and product-specific factors influence the equilibrium of virtual showroom deployment. A decrease in development costs may lead to a shift in the equilibrium strategy of whether to deploy virtual showrooms[68]. Moreover, due to the ongoing pandemic preventing consumers from frequenting beauty counters, L’Oréal is currently promoting Modiface AR technology to help customers try out makeup products, such as lipstick shades and hair colors, through their smartphone cameras[69].

Education and teaching

The field of education holds the most promise for the metaverse[70]. The term “university” refers to both higher education institutions and the metaverse, and there is a natural parallel and coverage between the metaverse and education. Humanity has entered a historical stage where “life is learning, and learning is life”. The metaverse provides the largest space and the best technological foundation for this. For example, open universities are very suitable in the metaverse, as it frees everyone from the constraints of physical campuses. Metaverse classrooms are full of imagination, where traditional teachers are no longer limited to classrooms and existing teaching tools. Graphics and formulas in a math class can be constantly combined and changed in geometric space, and the process of the metaverse’s birth and development can be presented right in front of the students. Students can even watch the rise and fall of dynasties with historical figures such as Qin Shi Huang in the metaverse, which are all changes that the metaverse brings to education.

For instance, Lee and Hwang chronicled the efforts of future English teachers to create VR materials for use in K-12 digital textbooks. They examined how these materials were connected to metaverse platforms to promote flexible, lifelong education[71]. To address the limitations of conventional approaches to remote practice education, Lee et al. presented a system that brings VR and metaverse techniques into the classroom. Besides, they developed an aircraft maintenance simulation metaverse based on the proposed system and conducted an experiment comparing this system with video training methods[72]. On both knowledge tests, the group that used the suggested system outperformed the group that watched training videos. The presence questionnaire results corroborated the participants’ reports of the metaverse system’s physical presence, lending credence to the practicality of the proposed system. It is evident that the metaverse allows students to have a more intense immersion experience in the teaching, unlike simple video instruction, which enhances students' interest and helps them to immerse themselves in the theoretical knowledge in the classroom[73].

Travel

The ability to travel will be another significant use for the metaverse. It's difficult to see the world's most famous landmarks and ancient ruins due to the limited availability of traditional travel options, especially during peak holiday seasons. Tourists will be able to "take depart without delay" by just donning VR glasses and viewing 3D views of space that have been digitally captured and shown in the cloud. Various explanations and simulated interactions help tourists gain an immersive experience beyond real tourism. For example, Matterport, a company specializing in 3D viewing, has launched the five ancient ruins of Egypt through VR technology. Once launched, it has been loved by everyone. Without crossing the border, tourists can immersively visit the relics of Egypt and learn about the historical allusions. With the use of Matterport, Tchomdji et al. created a metaverse in which users can observe 3D models of academic structures and real-time tours of their interiors. Users can view the 3D model of the university's infrastructure from afar on the website after it has been uploaded for real-time display[74]. As Disney's CEO put it, "the metaverse is Disney's future"[75]. Disney has not revealed the specifics of their foray into the metaverse, but by doing so, they were able to build an entirely new metaverse. For instance, visitors to the virtual Disneyland can interact with numerous Disney characters in the form of their digital selves, engaging in conversations, dances, and games. This suggests that Disney World is, in fact, the "most tranquil spot in the multiverse".

Table 2 summarizes the platforms and technologies utilized in the various metaverse applications.

Table 2. Metaverse application progress

Field	Name	Technology type	Progress
Game	Axie Infinity	Pet trading and fighting games	Play-to-Earn mode, players design their own pet image
	Decentraland	Virtual platform	Virtual assets support the owner in creating arbitrarily
	Roblox	Multiplayer online sandbox game creation platform	Players design their own items, create different types of games
Industrial manufacturing	Omniverse	Industrial metaverse	(1) Multiple people co-create content on the platform (2) Full-cycle operation simulation supported by DTs (3) Virtual Factory Collaborative Manufacturing
Telecommuting/video conferencing	Google's "Project Starline" program	Google's "Project Starline" program	(1) 3D remote interaction (2) Observing the chat object (3) Eye-body interaction
	Facebook launches Horizon Workrooms	Remote collaboration	Face-to-face communication in virtual conference rooms
Shopping	"The Gucci Garden Experience" Virtual Exhibition	Virtual shopping	Exhibit and shop virtual items
	3D Tmall Home Improvement City	An immersive experience of home improvement environment	360° presentation of furniture decoration effect
Travel	Matterport	3D viewing	Remote Tour of University Buildings
		Virtual Disney	Players talk, dance, and play games with various Disney characters

Metaverse redefines the relationship between people and space. Pathways to the metaverse are being established with the help of technologies like AR, VR, cloud computing, 5G wireless, and blockchain, all offering interactive means of mixing virtuality with reality. This transformation is changing and disrupting various industries in our daily lives.

AR is a new technology that integrates virtual elements into the real world through a camera. It is commonly used in games like Pokemon GO and Microsoft HoloLens. Virtual Reality (VR) is an interactive 3D environment that enables users to experience a virtual world. In the metaverse, VR can be used to explore star systems and analyze material structures. Cloud computing is a model that shares computing resources and information to provide services. In the metaverse, it can store big data, remote sensing images, and metaverse research information, helping scholars understand and study the universe better. 5G wireless is a new mobile communication technology that can provide good network coverage and connectivity. In the metaverse, 5G technology can help launch satellites to collect information about the universe. Blockchain is a distributed recording and storage technology that creates verifiable databases through a P_2P network. In the metaverse, blockchain can record information about the universe, such as interstellar travel, to help document the universe's history. This can enable future scholars to explore the connections between countless star systems

4. Advances in VR technology in the 4D metaverse

As the country's scientific and technological in-frastructure has improved, VR has found its way into more and more aspects of everyday life in China. Especially after the advent of the metaverse in 2021, VR has become an integral part of everyday life and a crucial entry point into the metaverse. Several cit-ies and even countries are paying close attention to this pattern[76-78]. "When you put on VR headsets and AR glasses, you are not simply watching information, but rather being involved in it", Mark Zuckerberg said of the metaverse. "You feel like you're with other people, doing things like dancing or fit-ness exercises". Yet, it remains unverified if the cur-rent metaverse VR research stage can reach such a condition. **Figure 4** depicts several notable research accomplishments in the realm of VR in the metaverse and their underlying software framework.

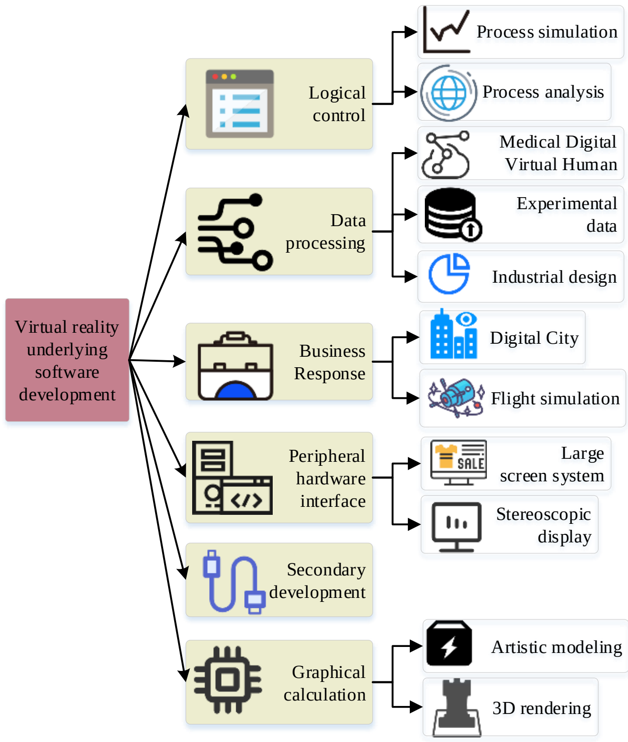

Figure 4. The underlying software framework of VR in the metaverse.

In spite of the proliferation of blockchain-based metaverse platforms, it is still unclear whether or not XR technology can significantly increase labor efficiency and production in the metaverse economy. Players' need for social interaction necessitates that workplace technology in the metaverse supports immersive job training, remote work, and virtual work meetings, as noted by Durana et al.[79]. Performance indicators for virtual work, remote workforce, and distant collaborative work can all benefit from the use of VR and text analysis techniques. Thus, Hawkins showed how a VR-based recruitment tool integrates sensory immersion, affective data, voice biometrics, and cognitive computing systems in a 3D digital world, workplace technology, and research in deep learning computer vision algorithms to facilitate virtual workforce training and skill development in an immersive metaverse environment[80].

In the field of healthcare, VR rehabilitation in the metaverse has shown significant potential in assisting various rehabilitation exercises, providing opportunities for clinical research, assessment, and intervention. Schweitzer and Rizzo noted that students with attention deficit hyperactivity disorder can benefit from the immersive experience of VR classrooms in the metaverse by learning to better regulate their impulsivity and attention deficit-related social difficulties[81]. Physiological measurements can be used in addition to clinical interviews and questionnaires to track patients' mental and physical health. In addition, Koo1 noted that the Seoul National University Hospital in South Korea has used metaverse and AR technologies to train surgeons in the treatment of lung cancer. More than two hundred thoracic surgeons from Asian countries took part in this training program, which involved experiencing VR scenarios on laptops or VR headsets and debating surgical techniques with their peers. This new approach to training is a major advancement in the history of medical education[82].

The appeal of the metaverse is not limited to the field of medicine; it is present in other areas of education as well. The scientific community, for instance, has been making attempts to aid governments around the world in their pursuit of environmental education. A revolutionary architecture of metaverse-based, fully immersive, three-dimensional VR for teaching about water resources was proposed by Lo and Tsai[83]. Students use this framework to enter an immersive environment in which they can experiment with and interact with 3D multimedia content in the metaverse while running specialized Android applications on a headset. By shaking their heads or moving interactive markers, students can trigger interactive actions such as replaying video segments, playing consecutive video clips, displaying text annotations, and completing questions relating to the course topics on soil and water conservation. Big data analysis of student work helps to enhance education by validating this study as a promising new multimedia education system.

Digital retail products and AR shopping tools may be able to improve computational efficiency by integrating customer information, context awareness, and brand recognition measures, as evidenced by the growing popularity of blockchain-based metaverse platforms. Metaverse stores offer a different level of customer assistance than their 2D counterparts (which are typically menu-driven). By conducting focus groups and key event methodologies with current users of metaverse retail stores, Gadalla et al. provided a methodology for improving the service quality of 3D metaverse stores for retailers[84]. Adams meantime investigated and synthesized metaverse applications of customer behavior, AR technology, and immersive visualization systems. By analyzing the customer's path to purchase, it is clear that we can better understand the role that tailored purchasing experiences play in acquiring virtual assets[85]. In addition, Han et al. offered a means of evading the VR experience, which allows users to spend several hours at a time inside a computer-generated world and engage with information while being protected from the harsh realities of the actual world outside. Such risky speculation adds intrigue and allure to the metaverse[86].

Although the metaverse allows for highly personalized avatar interaction, it does have several downsides, most notably in the areas of privacy and identity security. Cybercriminals may gain access to users' avatars, digital assets, and personally identifiable information when they enter the metaverse using VR human-machine devices. Therefore, Tran et al. introduced a specific vein recognition method for VR human-machine devices in metaverse to prevent identity theft. They also developed a vein recognition system based on convolutional neural networks and anti-aliasing techniques, which is more secure in personal verification compared to other manually-based biometric features such as fingerprints and palm prints[87]. Kozinets followed established methodological criteria and applied logic to construct a scope, definition, and assembly of a new kind of web photography (immersive web photography) for study into immersive technology. Three significant practical limits to developing high-quality web photography are limited time, finances, and researchers' limited skill sets. These restrictions expose metaverse users to potential privacy breaches whenever they interact with others[88].

While the metaverse's wearable technology has great promise for facilitating user contact with highly configurable digital avatars, addressing users' emotional requirements remains challenging. This results from a collection of customer optimization strategies, aesthetic design features and criteria, and the complexity of understanding user preferences, enabling product functionalities, and other considerations. Kwok and Tang proposed a complex optimization technique called the fuzzy multi-criteria decision-making method, which uses fuzzy-based hybrid analytic hierarchy process and integral-based approaches to determine the key factors and design parameters of VR headsets to understand customer preferences and the technical requirements of engineering product shells, allowing the headset to meet the demands of the visualized metavehicle[89]. Shin explored how user perception is generated and executed in an extended context, focusing on how user internalization and embodied experiences affect user experiences. According to the study's findings, users influence the metaverse based on their own levels of visibility[90]. The metaverse becomes a structural element that influences and limits user behavior, yielding useful information for device design.

VR is undeniably a new spatial computing technology that collects and analyzes information about its users (including their bodies and their interface with hardware). Concerns regarding who will gain from VR as a data-intensive technology and where possible risks of data dissemination may lie are developing, as they have with previous kinds of digital media. The case of Facebook's Oculus VR, the industry standard in VR and a key component of their metaverse goals, was examined by Egliston and Carter[91]. In this scenario, it is stated that the data-intensive nature of VR creates problems such as power imbalances, the possible worsening of income disparity, algorithmic biases, and new kinds of digital exclusion.

Table 3 lists the technical results of the above research.

Table 3. Advances in VR technology in the metaverse (partial results display)

Author	Type	Technical achievements	Limitations
Kozinets[88]	Immersive Webcam	Comprehensive research on AR, VR, and metaverse phenomenological service experience	The rapidly changing environment and scarce time resources cannot be fully satisfied
Pan et al.[96]	Virtual digital human	Photoscan technology and Unreal Engine 5 Metahuman	Single-player type
Gadalla et al.[84]	Virtual shopping	Human contact, emotional expressiveness, virtual experimentation, and fantasy production	Insufficient test cases and unsatisfactory stability
Alpala et al.[78]	Digital factory metaverse	(1) Display audio and video presentations (2) Multi-user team collaboration custom configuration (3) High-quality textured realistic scenes	(1) User avatars cannot be customized (2) Not fully applicable to low-end computers (3) The performance in the real environment needs to be verified
Tran et al.[87]	Metaverse VR human-machine device vein recognition	(1) Human-machine device finger vein recognition method (2) Finger Vein Recognition System (3) The accuracy rate increased to 97.66%	Not available for all wearables
Kwok and Tang[89]	Wearable device	Optimization of earphone parameters by fuzzy multi-criteria decision-making method	Lack of robustness of the product
Lo and Tsai[83]	Metaverse 3D VR architecture	(1) 3D VR multimedia content interaction (2) Shake your head to move the interactive sign	There is no specific verification of the learning effect.
Koo[82]	Metaverse medical training	(1) Multi-person interaction (2) Restoration of real surgical scenes (3) Panoramic live broadcast of VR cameras	It cannot be used universally, requires sufficient hardware support, and the effect of a broader range of personnel participation needs to be verified.

In light of the aforementioned findings, we can say that the metaverse is a digital metaverse where DTs of people, places, and things coexist virtually. VR and AR are crucial for the realization of a true metaverse. The metaverse, however, is not restricted to VR. Devices that use AR technology and those that connect to the Internet are both essential to making the metaverse a reality. The metaverse is a virtual environment that may be accessed in a number of different ways. There has been development and success in many other industries, including medicine, gaming, entertainment, education, and even online trade. The metaverse is a free, online, 3D virtual realm where users can meet and engage with others through the use of personalized digital characters called "avatars." In the virtual world, users have the option to purchase virtual currency, props, and even digital assets of their very own. This reflects that users can experience a level of immersion in the metaverse comparable to that in the real world; however, perfect solutions to the legal, privacy, transmission, and property security concerns associated with this experience are still lacking and are still being explored.

The current state of VR in the metaverse, as evidenced by a number of recent successes, makes it possible for users to enter the metaverse via wearable devices and for numerous users to communicate and engage with one another. Users can use gestures to control virtual characters and even replicate the experiences of those characters. VR technology has various potential applications, but it has gained the most notoriety in the entertainment sector. In contrast, the metaverse can be considered a more developed form of a 3D internet, and its effects on people's professional and personal lives are likely to be more far-reaching.

5. Advances in human-computer interaction technology in the 5-Dimensional metaverse

From what has been uncovered, it can be said that the metaverse is a 3D virtual world that can be accessed by means of VR gear or web browsers. Users are able to navigate this environment by using gaze, speech, and feedback controls[92]. Users of VR hardware can experience the inner workings of this simulated environment. In the metaverse, individuals can engage in a wide range of activities, from conducting business to enjoying entertainment and even going on vacation. Developments in the field of human-computer interaction have accompanied every game-changing invention in the digital economy's history. **Figure 5** depicts these developmental stages of human-computer interaction.

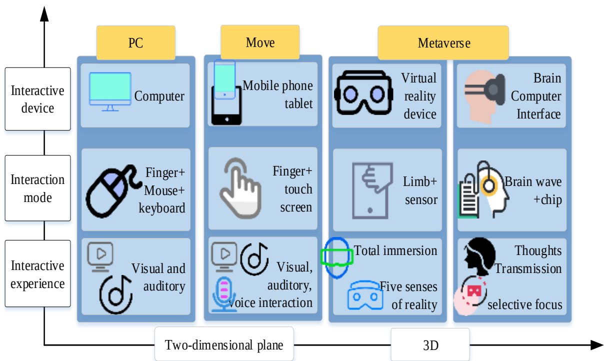

Figure 5. Evolution process of human-computer interaction mode.

The exponential growth of AI and XR has revealed that the nature of the human-computer connection is shifting from gradual evolution to radical reconstruction. Human-machine interaction, interaction scenarios, and interaction experiences have all been rethought in light of the metaverse notion.

Recent advancements in areas like human-computer interaction, the IoT, cloud and edge computing, blockchain, non-fungible tokens, and high-performance computing infrastructure have spawned a plethora of novel use cases for both XR and the metaverse[93]. Future advancements in multi-access networks, 6G technology, and the implementation of AI will make it possible to serve billions of users and create a shared metaverse that blends the virtual and real worlds into one seamless experience. The evolution of human-computer interaction may be loosely broken down into three stages: the personal computer Internet era, the mobile Internet era, and the metaverse era. The shift of interaction modes and devices is one of the most significant expressions of the new human-computer interaction. As technology continues to evolve and develop, human-computer interaction modes are constantly enriched and upgraded in terms of content and scenarios. The following sections will analyze specific application cases in conjunction with the literature.

In the previous paragraph, the advancement of VR technology has paved the way for the development of wearable devices, enabling somatic sensations and bringing more comprehensive perception and feedback in the metaverse-based virtual society. Based on these findings, Sun et al. presented a haptic perception and haptic feedback environment with multimodal sensing and feedback capabilities[94]. This unified setup features vibrators and nickel-chromium alloy heaters for haptic feedback through vibration and thermal haptic sensation and friction-based and thermoelectric sensors for haptic and temperature awareness. Through friction-based haptic sensors, this new human-computer interface can accomplish high-resolution continuous finger motion tracking, allowing for exceptional gesture/object recognition performance based on AI analysis. An interactive metaverse platform with cross-space perception capability has been successfully realized through the integration of multimodal perception and feedback capabilities. It sallows users to have face-to-face immersive virtual social experiences, much like the characters in The *Three-Body Problem* transmitting their in-game sensations to their real-world selves.

Le et al. noted that in addition to wearable devices, the interaction interface of the metaverse is also an important device[95]. A minimalist, low-power, and multimodal non-contact interaction interface has been created through the integration of complementary data from humidity sensors in micro-electro-mechanical systems and sensors based on friction. In this research, a friction-based sensor based on two annular aluminum electrodes was developed to facilitate the rapid recognition of multidirectional finger movements by the interface. Experiments using the proposed interaction interface have been successfully applied to a game control interface for manipulating virtual cars in VR space and a password input interface for high-security 3D passwords. The latter uses the resonance frequency change of the humidity sensor and the output voltage waveform of the friction-based sensor. The results showed that this novel multimodal non-contact interaction interface has vast promise in a wide variety of future metaverse applications.

There has been a rise in the popularity of projection-based display environments. There is little effect on human-computer interaction or user-to-user communication/collaboration modes because these systems are typically only used in laboratories or for other specialized applications. In contrast, metaverse systems allow for an unlimited number of projectors to automatically self-calibrate, drastically reducing the complexity of both installation and upkeep. To further improve system scalability and encourage collaboration among metaverse users, the metaverse also enables unique communication paradigms. Multi-sensory technologies, for instance, make it possible for people to share and learn from each other's sensory experiences online. Panagiotakopoulos et al. discussed the commercial uses of sensory Internet and 6G, which add to the closeness of multi-sensory experiences in the real world, and described the practical applications of this technology in digital communication, marketing, and well-being[96]. In addition, they advocate for a mutually beneficial partnership between the Internet of Senses and the metaverse, with 6G acting as an essential catalyst for future multi-sensory experiences.

In this regard, Lv et al. examined the use of DTs models to transfer tangible and intangible real-world objects to the metaverse from multiple perspectives[97]. For instance, the metaverse provides a new way for elderly people to evade the constraints of reality and engage in continuous and consistent social activities to combat loneliness. Using metaverse-related technologies and human-computer interaction tools, Liang et al. developed a framework for a virtual social center for the elderly and designed a prototype system based on this framework[98]. Case study data from a prestigious medical center corroborated the findings, demonstrating that the elderly who had used the virtual social center reported considerably higher levels of psychological health than their counterparts who had not. These results were supported by data from a case study conducted at a renowned medical center, which showed that elderly people who had utilized the virtual social center also reported significantly higher levels of psychological health than their non-using peers. Children with autism spectrum disorders who took part in the study were given access to a metaverse-based social skills training program developed by Lee et al.[99]. Once every week for 60 minutes for a total of four weeks, the treatment group will engage in the study team's metaverse-based social skills training program. These findings provide credence to the promise of a metaverse-based relational skills education and enrichment program for helping autistic youngsters learn social skills.

Nowadays, human-computer interaction in computational materials science is mainly achieved through encoding in software or neural networks, with the latter being used in the realm of education and training. The global spread of the COVID-19 epidemic has led several nations to embrace video conferencing software platforms for distance education. The emergence of the metaverse as a potential answer to this problem lies in the hybrid physical-digital space it creates. There should be a concerted effort across several fields to digitize human intelligence. For this purpose, Gao et al. developed a metaverse framework for materials science computation. In this system, humans, data from experiments, and theoretical models can all work together[100]. This metaverse platform allows users to optimize their interactions with water, delving into water's features, including its liquid and solid phases, and creating new potential water fields and novel ice polycrystals. Access to such a platform would surely be a major catalyst for a paradigm shift in computational materials science by providing invaluable insights for its future growth.

In their proposal, Arif and Hayati suggested using a metaverse-based mathematics teaching medium outfitted with a Learning Management System (LMS) that dynamically adjusts topic selection in accordance with students' individual skill sets[101]. The Unity game engine was used to create an educational system that aids the LMS in making topic selections by delivering recommendations based on a number of parameters. In this teaching methodology, scenes are represented by beams, cubes, prisms, and pyramids. The findings of the pre-test and post-test reveal that the LMS successfully carries out its duties by adaptively picking topic scenes based on students' performance. This suggests that skillfully implementing gamification aspects into metaverse design can increase student engagement and aid in the retention of course materials.

Wang et al. proposed recommendations for virtual-physical hybrid classroom configurations to bring together students and teachers in a shared educational metaverse to facilitate real-time synchronization of large numbers of participants and activities in physical mixed reality (MR) classrooms and virtual remote VR platforms[102]. This human-computer interaction approach attempts to transform traditional physical classrooms into virtual physical network spaces, creating a new social network where learners and educators are connected on an unprecedented scale. Jovanovi and Milosavljevi presented a fresh platform with supplementary tools for developing educational experiences in virtual worlds, allowing them to circumvent the restrictions imposed by the COVID-19 epidemic[103]. Using the Mannien matrix, they evaluated and assessed the implemented VoRtex prototype against well-known virtual world platforms in order to determine how well each one supports collaborative learning activities in virtual environments.

In the field of aircraft maintenance, metaverse, and MR offer significant opportunities for interaction with virtual aircraft (DTs). Using a deep learning voice interaction module, Siyaev and Jo presented MR education and training for Boeing 737 smart glasses aviation maintenance, enabling trainee engineers to command virtual assets and workflows using their voice[104]. They used a convolutional neural network architecture to handle auditory features, and they recognized commands and languages by learning and classifying mixed requests in English and Korean and delivering related feedback[105]. By proposing a voice interaction module, this novel human-computer interaction solution improves teaching and training in aircraft maintenance metaverses by allowing for intuitive and efficient control of operations and facilitating enhanced engagement with virtual objects in MR. **Table 4** summarizes the recent developments in human-computer interaction inside the metaverse.

Table 4. Progress of human-computer interaction technology in the metaverse (partial achievement display)

Author	Type	Technical achievements	Limitations
Liang et al.[98]	Metaverse virtual social platform	Virtual social hub reduces loneliness and depression in older adults	Elderly people have limited ability to operate.
Wang et al.[102]	Educational metaverse	Real-time synchronization of participants and activities in MR classrooms and virtual learning spaces	Ability to operate concurrently with users who do not have a larger capacity
Gao et al.[75]	Metaverse computing platform for materials science	Unifying Human Intelligence, Experimental Data, and Theoretical Simulations	How to ensure the stability of generated crystals in the virtual environment.
Siyaev and Jo[104]	Aircraft maintenance metaverse	(1) Smart Glasses Aircraft Maintenance (2) Bilingual mixed request processing	Recognition of other languages is not covered.
Arif and Hayati[101]	Teaching system	Mathematics teaching metaverse combining gamification elements	Theme scene assignment accuracy is low.
Jovanović and Milosavljević[103]	Teaching platform	VoRtex platform for online teaching (virtual classroom, intelligent agent, interactive open space)	It can't fully realize the same feeling as the virtual character.
Sun et al.[94]	Multimodal sensing perception and haptic feedback loop	An interactive metaverse with cross-spatial awareness	To be verified by more cases
Lee et al.[99]	Multimodal non-contact human-computer interaction interface	The game control interface for manipulating the car and the three-dimensional password input interface successfully completed the interaction.	Applications in the metaverse need to be proven.

The social impact of the metaverse's growth is expected to outweigh that of the mobile Internet by a wide margin. The fundamental goal of human-computer interaction in the metaverse stage is to improve the realism of user experiences. In this phase, efforts are directed toward expanding the capabilities of VR, AR, and tracking systems so that consumers can have more natural and realistic interactions with products. Later on in the metaverse's development, mass-produced, anthropomorphic, interactive virtual beings will penetrate the real world via human-computer interaction. There will be widespread manufacturing of interactive machines. Digital avatars allow users to serve as agents in a variety of circumstances, allowing them to interact with and influence other characters. Future possibilities of human-computer interaction will involve three-dimensional information exchange in the virtual world and hybrid places that combine elements of the actual and virtual worlds. This means that the potential for fields like gaming, education, exhibits, industrial manufacturing, design planning, and public services will expand to include more sophisticated forms of human-computer interaction than are currently possible.

6. Potential future research directions in the metaverse field

The metaverse is a complex and rapidly evolving concept that encompasses various cutting-edge technologies, including artificial intelligence, DTs, blockchain, cloud computing, augmented reality, robotics, brain-computer interfaces, and 5G. The metaverse's ecosystem comprises foundational technology support, front-end device platforms, and scene content entry points. Three key attributes define the metaverse: spatiotemporal (including time and space), human-machine (including virtual people, natural people, and robots), and economic value (based on blockchain).

The speed of metaverse development in different industries varies significantly, with those closely related to the metaverse's three attributes developing faster. This includes games, exhibitions, education, design and planning, healthcare, industrial manufacturing, government public services, and more. In the future, all industries will need to adapt to the metaverse's unique attributes.

Currently, there are four narrative logics for metaverse companies in the market, including virtual and real fusion, decentralized transactions, free creation, and social collaboration. Major technology companies rely on existing advantages to lay out the metaverse field. There are three main modes: focusing on core components and basic platforms, accelerating the research and development of metaverse-related hardware; focusing on business models and content scenes, exploring metaverse-related application scenarios; and government-driven corporate entry.

South Korea is one of the most active countries in promoting the development of the metaverse industry. Its capital, Seoul, has announced plans to become the first city government to join the metaverse. Meanwhile, the development of the metaverse industry in South Korea is mainly led by relevant government departments, guiding and promoting companies such as Samsung, Hyundai, and LG to form the "Metaverse Alliance" to establish a national metaverse development platform.

However, the global development of the metaverse industry is uneven, and companies need to strengthen their technological capabilities. The metaverse still faces challenges in many fields, including security, education, talent development, regional development balance, and technology inbreeding. For example, how to achieve trusted minimum authorization under zero-trust security technology in the metaverse, how to apply real-world privacy computing, and how to adapt talent and basic education to the development of the metaverse technology industry.

7. Conclusions

Several multi-interface metaverse ecosystems are forming gradually in response to diverse new demands. The profound shifts in people's jobs and lives that metaverse will bring are only beginning to show themselves. Case studies of metaverse development in sectors as varied as gaming, teleconferencing, education, commerce, manufacturing, and travel are the focus of this paper. This paper also explores the current state of VR and human-computer interaction technology in the metaverse, highlighting developments, roadblocks, and inevitabilities in this study area. From the viewpoint of technological advances, the rise of new technologies such as big data, cloud computing, AI, 5G connectivity, and blockchain in the Internet era has shifted the focus from isolated innovation to widespread participation. As more and more technologies are incorporated, metaverse applications are maturing. The metaverse is still in its infancy from a business model standpoint, so there is a lot of room for creativity in the market. Big names in tech as well as startups with fresh ideas, have entered the race. The scope of the metaverse has grown beyond its original use cases in the realms of gaming, entertainment, and social applications, with growing evidence of its implementation in fields including medicine, teaching, and manufacturing. The period of data has arrived, and while it may be premature to term this the metaverse era, there's no denying it. Data serves both the backbone and algorithmic support for both AI and blockchain. However, the metaverse is a virtual world constructed by data, and once issues such as virus intrusion or account theft occur, it will have serious consequences. Therefore, data security remains a top priority. Consequently, a sustainable development ecosystem must be established for the future of the metaverse, which necessitates rejecting the bubble and proliferation, laying a solid foundation in the initial stage, gradually improving various structures and frameworks, and systematically solving many challenges.

Conflict of interest

The authors declare no conflict of interest.

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