Integration of Digital Twins, Blockchain and AI in Metaverse: Enabling Technologies and Challenges

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Chapter 3
Integration of Digital Twins, Blockchain and AI in Metaverse
Enabling Technologies and Challenges

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3.1 Introduction

Metaverse first appeared in Neal Stephenson's novel Snow Crash in 1992 (Joshua 2017). The fast rise of blockchain, the so-called Internet of Things or IoT, Virtual Reality (VR) and Augmented Reality (AR), Artificial Intelligence or AI, cloud and edge computing, and other technologies has led to the term "metaverse" become one of the most prominent buzzwords in the IT sector (Yang et al. 2022). Consider a computer-based or virtual world where you can locate tangible objects, friends, buildings, and universe information. The terms "meta" and "universe" combine to generate the word "metaverse," which refers to a three-dimensional (3D)

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virtual environment that attempts to mirror the actual world as closely as possible (Far and Rad 2022).

Although the metaverse is the successor of the internet, today's edge devices may not meet the high-specification requirements of showing high-definition 3D settings. Users must be able to access the metaverse to succeed as the next-generation internet, much as the internet entertains billions of people daily (Xu et al. 2022). Because the tactile internet, VR, and AR are important parts of 6-G, new communication technologies will be developed to enable the Metaverse (Saad et al. 2019). Furthermore, the current trend away from traditional communication measures such as data rates, and toward co-designing computation and communication systems, such as computation-oriented communication (COC) (Letaief et al. 2021), indicates that the next-generation mobile edge networks would help to distribute the metaverse to mobile users with computational limitations (Xu et al. 2022).

Users are given natural feelings via high-level and realistic simulation, which greatly improves technology and enables designers to foresee future consequences of items and minimize probable difficulties (Thomas 1999). Digital twins (DTs) are the most realistic physical simulations available, accurately signaling and predicting all of the computer's physical output (Tao et al. 2018). Metaverse is projected to connect the actual and virtual worlds by employing DT to create a virtual reproduction of the real environment (Wu et al. 2021). The rigorous sensor, communication, and processor requirements impeded the metaverse's real-time and scalable implementation (Xu et al. 2022). VR and AR headsets are two gadgets; AI and Machine Learning or ML are scientific and technological areas that have significantly advanced the metaverse and virtual worlds in addition to VR and AR (Khurana et al. 2019).

Blockchain technology will be critical in achieving the metaverse at mobile edge networks due to the "Internet of Everything's" paradigm shift from large data to decentralized small data (Saad et al. 2019, Xu et al. 2022). Blockchain is expected to bring up new possibilities in the metaverse, resulting in a new wave of technical innovation and the industrial revolution (Yang et al. 2022). On the other hand, barriers to metaverse development can be overcome through recent AI breakthroughs, big data analytics, AI-powered content creation, and intelligence distribution. As a result, combining AI and metaverse technologies has become a possible trend for promoting the positive growth of the blockchain/AI-powered metaverse ecosystem (Yang et al. 2022).

On the other hand, combining AI and blockchain with the metaverse poses significant research hurdles. Because of the characteristics of digital commodities and marketplaces, transaction volumes in metaverse systems are substantially greater compared to the physical world. Non-fungible

Tokens (NFT) on the Blockchain allow avatars to create content that can be sold for digital certificates (Nadini et al. 2021, Lambert 2021). This chapter discusses the integration of DT, Blockchain, and AI in Metaverse, emphasizing enabling technologies and difficulties.

3.2 Metaverse Enabling Technologies and Ecosystems

As shown in Fig. 3.1, integrating the real world along with its digital counterparts and moving toward the metaverse necessitates the inclusion of technologies like blockchain, computer vision, distributed networks, cloud computing, object identification, as well as ecosystem concerns like avatar, content production, social acceptability, accountability, security, and privacy. Figure 3.1 illustrates an overview of the major subjects in the context of technology and the ecosystem.

The two types' focus zones are shown in Fig. 3.2, where technology permits the metaverse to function as a vast application. Extended reality (XR) and user interaction techniques, which come under the technology

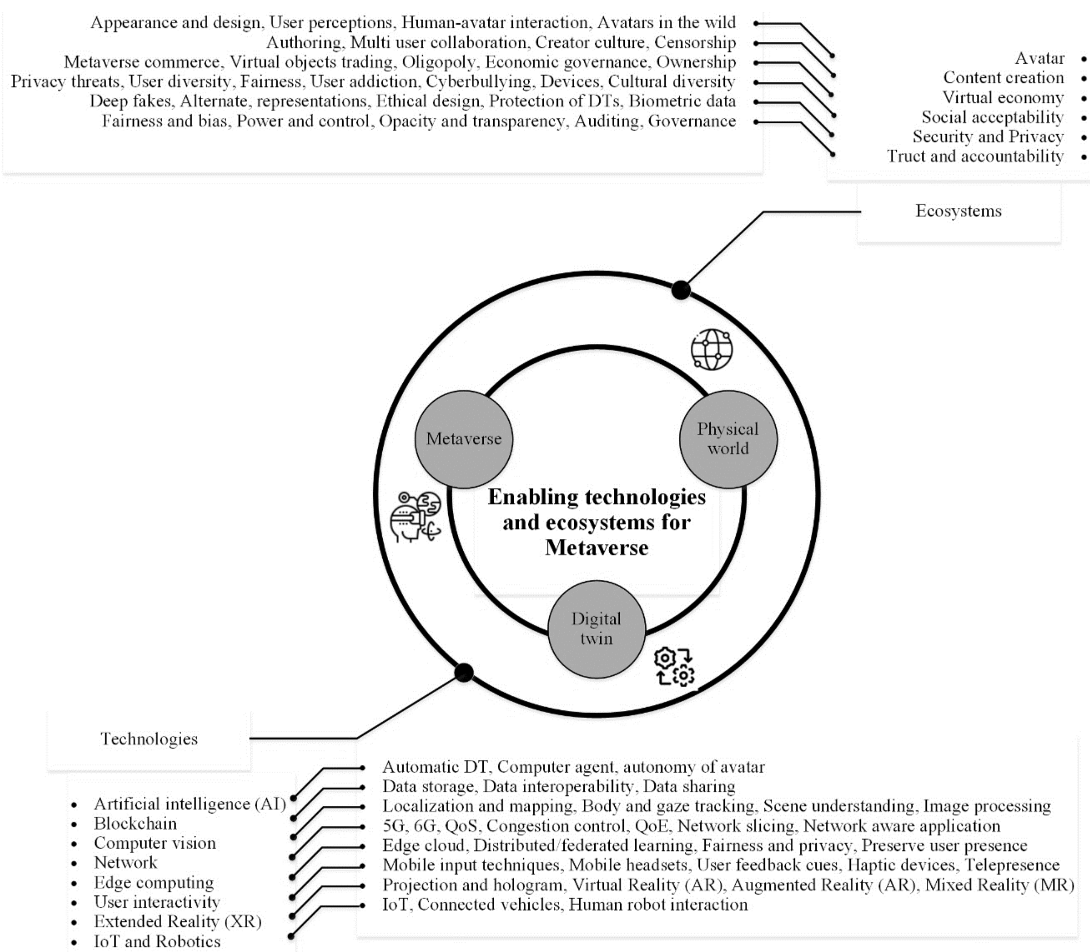

Figure 3.1: Enabling technologies and ecosystems for Metaverse (Adapted from Lee et al. 2021a).

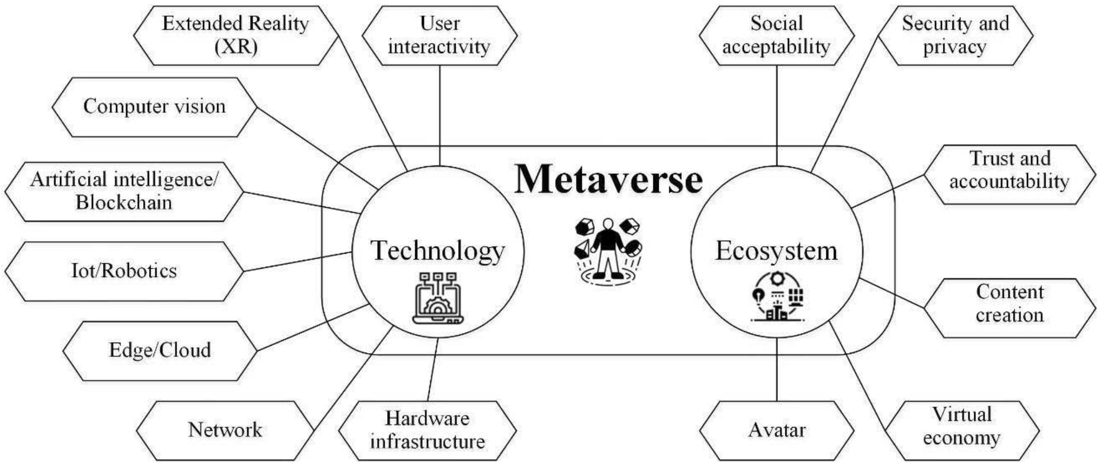

Figure 3.2: The metaverse's primary areas divided into technology and ecosystem (Adapted from Lee et al. 2021a).

side of the eight pillars, may be used to enter the metaverse by humans, such as manipulating virtual objects. User interaction with XR enables the completion of different activities within computer vision or CV, AI, blockchain, robots, IoT, and the metaverse.

The efficiency of latency-sensitive and bandwidth-hungry applications can be enhanced through edge computing. The local data source is operated as preprocessing data by using edge devices. Cloud computing, on the other hand, is known for its highly scalable processing and storage power.

Combining cloud and edge-based services may result in synergies such as increased application performance and user experiences. Consequently, with the right hardware infrastructure, edge devices, and cloud services, CV, AI, robots, and IoT might be enabled, as well as a better mobile network. An ecosystem is a self-contained, meta-sized virtual habitat modeled after reality. In the real world, human users may utilize XR and user interaction techniques to control their avatars for community activities like content creation. These Metaverse activities have naturally led to the creation of a virtual economy. The three main problems we deal with are social acceptability, security and privacy, and trust and accountability. Ownership of virtual economic products, for example, should be kept, and avatars must recognize the impacts of such items; human users exist inside the metaverse and want their behaviors to be free of privacy and security concerns (Lee et al. 2021a). Figure 3.2 displays the major technologies that ignited the 'Digital Big Bang.'

3.3 Metaverse Artificial Intelligence (AI)

AI promises to be able to explain every aspect of learning (Dick 2019). Modern AI research emphasizes ML, deep learning (DL), and reinforcement learning in computer vision, decision-making, and natural language processing (NLP). Individuals are naturally drawn to using artificial intelligence to materialize the metaverse due to real-world developments in AI (Yang et al. 2022).

3.3.1 Typical AI Algorithms

Computer learning approaches, such as linear regression (Jammalamadaka 2003), random forest (Oshiro et al. 2012), and decomposition of the singular value (Paige and Saunders 1981), enable machines to learn from experience and data in the same manner that people do. The support vector machine (Vapnik 1999), for example, is a sample machine learning method used for pattern categorization, regression, and learning a ranking function.

Convolutional neural networks (CNNs and also known as ConvNets in Fig. 3.3(b)) are deep neural networks influenced by biological neural networks. Conventional CNNs use a convolution kernel with a shared-weight design to create equivariant translation responses or feature maps. CNN includes convolution, pooling, and fully connected layers (Ketkar and Moolayil 2021). CNN uses a technique known as weight sharing across neurons to achieve a large decrease in size. Consequently, CNNs have supervised learning algorithms that may be used in various computer vision applications, including augmented reality, image search, and face recognition.

Reinforcement learning describes an agent's sequential decision-making problem while interacting with a dynamic environment. Experience is earned via trial and error (Kaebling et al. 1996). Figure 3.3(c) shows the RL schematic. When paired with Markov Decision Processes (MDPs) (Van der Wal 1980) and deep neural networks, deep reinforcement learning has the potential to transform AI. It represents a step toward constructing an autonomous system with an understanding of the visual world, as Arulkumaran et al. (2017) declared. Value functions and policy search are two strategies for RL problem-solving. Asynchronous benefit actor-critic advancements and deep learning-based RL (DRL) algorithm optimization (TRPO) have been found. These DRL algorithms can surpass humans in some fields (Arulkumaran et al. 2017).

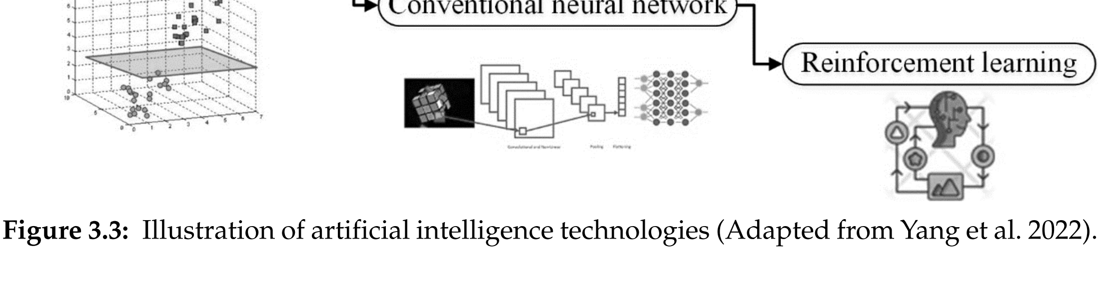

Figure 3.3: Illustration of artificial intelligence technologies (Adapted from Yang et al. 2022).

3.3.2 Metaverse AI-based Activities

Ando et al. (2012) provide a technique for inferring seen exhibits from a Second Life mobility log in a metaverse museum. They must first detect which exhibits the user sees by focusing on the avatar's status to deploy recommendation systems in metaverse museums and complete this job quickly and correctly.

Yampolskiy et al. (2012) describe methods for accurately assessing and recognizing avatar faces. The prototype uses a causal engine based on the unreal tournament gaming engine. This engine bypasses the native physics engine to provide alternate outcomes to competitor actions. Civilization VI, Stellaris, and the research game Prom Week can be examined to evaluate human-centered artificial intelligence-based games through the evaluation technique mentioned by Kreminski et al. (2019). Existing assessment approaches make it difficult to comprehend, such as the normal narrative framework players have in their heads when playing a game. In a game, many subjective experience narratives may occur.

DRL is expected to be a viable solution for automated trading in the open and decentralized metaverse environment since it enables a well-trained agent to make decisions automatically (Puder et al. 1995). According to Liu et al. (2021a, 2021b), the proper use of AI will transform from conventional exchange to a robotized machine learning technique. As a result, Liu et al. (2021a) offer FinRL, a DRL-based system that can effectively design a multi-factor model for ecosystem trade automation to decrease the simulation-to-reality gap and data processing overhead (Liu et al. 2021b).

3.4 Metaverse Blockchain

Blockchain is widely considered to be one of the metaverse's fundamental infrastructures. Blockchain is expected to link disparate small industries and create a stable economic structure, enabling the metaverse to have transparent, open, efficient, and trustworthy rules (Yang et al. 2022). Data traceability and secrecy are provided to metaverse users through hash algorithms and timestamp technologies, for example. The traditional Blockchain architecture comprises network, data, consensus, application, and contract layers. The following is a list of the connections between those levels and the metaverse:

- Data verification and transmission methodologies provide network support for diversified data transfer and metaverse economic system verification.

- The credit issue of metaverse transactions is solved via consensus procedures.
- Blockchain distributed storage assures the protection of virtual assets and metaverse users' identities.
- Smart contract technology ensures that all Metaverse members are in a secure environment. It implements Metaverse value exchange and ensures that system rules specified in contract codes are executed transparently. Smart contracts' codes can't be updated after they've been deployed. The terms of such smart contracts must be followed to the letter.

Metaverse economic systems, as demonstrated in Fig. 3.4, need decentralized exchanges to support cross-chain circulation tokens or NFTs. Based on the decentralized exchange protocol, Tian et al. (2021) propose a decentralized cryptocurrency trading system. This system selects trustworthy people for validation by using two forms of consensus techniques, such as PoW and Proof of Deposit. The number of participants,

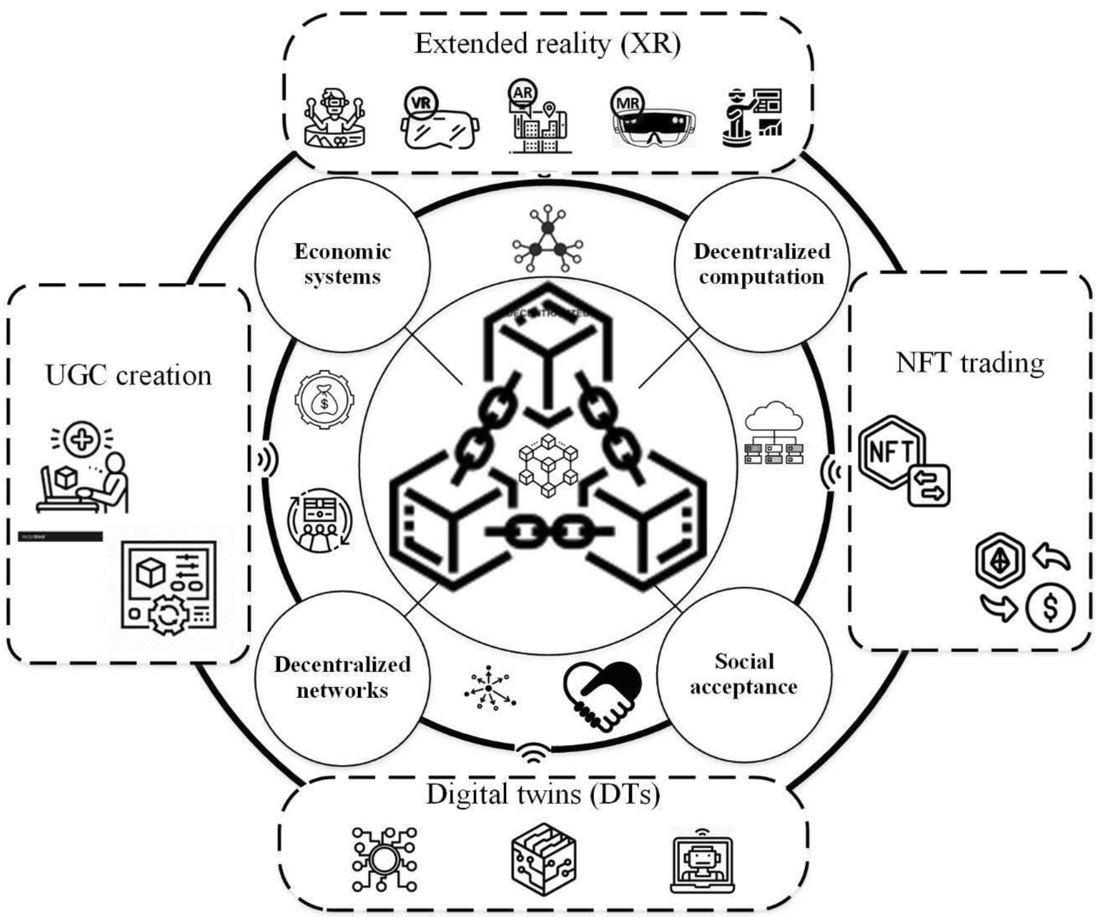

Figure 3.4: Different scenarios of wireless blockchain for virtual and physical services in the Metaverse (Adapted from Xu et al. 2022).

not the number of transactions done by a single participant, determines platform overhead such as provisioning and execution charges.

The economic loop of user-generated digital content is represented, minted as NFTs, and traded for bitcoin. For financial systems, avatar society, and edge resource management, the cooperation of numerous blockchains is depicted.

3.4.1 Metaverse Transaction Characteristics

The metaverse features many financial facts: estate purchases, item rentals, service purchases, and almost anything else that exists in reality. Consequently, Metaverse transactions are not confined to intra-metaverse or token transfers.

On a typical blockchain, when a transaction is started, it is transmitted to miners and kept in localized transaction pools. The miner chooses transactions to agree on and then utilizes hash-based consensus. The first miner that discovers a printing of the puzzle that satisfies the stated difficulty will upload the block to the chain and notify all other miners. Because the metaverse leads trading in the digital world every second while utilizing numerous intraoral inter-metaverse apps, these blockchain nodes are anticipated to handle many transactions. Full blockchain nodes in the metaverse must, as is common, maintain all previous transactions locally, putting huge pressure on the full nodes.

Another problem with metaverse transactions is ensuring that confirmation latency is kept to a minimum. End-to-end latency for Internet apps that cater to human behaviors is measured in milliseconds. Furthermore, metaverse applications based on 3D display and interaction need a 10-millisecond delay to avoid vertigo. Metaverse transactions must have a low confirmation latency for these low-latency applications.

3.4.2 Blockchain-empowered Market in Metaverse

Decentralized finance (DeFi), made possible by modern blockchain technology, has the potential to boost the metaverse's decentralized market and commerce. This section looks at several common studies related to the DeFi market and industry. Daian et al. (2020) investigated the behavior of cryptocurrency arbitrage bots, who may watch transactions in the transaction pool and arbitrage. Daian et al. (2020) also proposed a cooperative strategy for optimizing arbitrage robot profit, as well as the fact that miners can behave as arbitrage robots in certain situations.

The MEV's so-called miner extractable value, on the other hand, may encourage the growth of diverging attacks. A cooperative bidding technique is offered to maximize profit. The monthly MEV supply is also more than 25 times the cost of a 51 percent attack on Ethereum (Daian et al. 2020).

DeFi is a revolutionary approach in the metaverse to construct imaginative economic structures, which are established mainly on smart contracts and fungible tokens or FT. Uniswap, an Ethereum-based decentralized exchange or DEX, offer users cash flows for their tokens (Angeris et al. 2019). DEXs are a new type of exchange that allows for safe peer-to-peer crypto-asset token trading (Dai 2020). The atomic swap is at the heart of a DEX, allowing multiple users to trade tokens or crypto-assets without needing a service provider. A peer-to-peer token trading platform is provided by Cybex (2021), a DEXs-based DApp. Cybex also uses the CYB token.

It should be noted that CYB may only be used to pay for new token exchanges, loan crypto-asset tokens, and Cybex market transaction charges. A network of validator nodes maintains the Diem Blockchain (2021), the payment system's technological backbone. Because blockchain software is open-source, anybody may build on it and expand their financial needs.

3.4.3 Authentication in the Metaverse Powered by Blockchain

The sale of virtual assets like land, rare items, valuable real estate, land development, leasing, gaming task rewards, and cryptocurrency investment returns are now the most important economic activities in the metaverse. Consequently, the metaverse presents a new kind of funding influenced by both the physical and virtual worlds.

The non-fungible token, or NFT, has traditionally been utilized to commemorate special anniversaries or amass digital assets. It recently merged with metaverse to launch a contemporary digital content enterprise (Etherium 2021, GDA 2021). NFT can secure the uniqueness of digital assets. The methodology behind this is recording encrypted transaction records on the blockchain. Tokens have a particular and recognizable value that may be used to verify who owns a digital asset. The blockchain-enabled NFT in the metaverse has been utilized to illustrate the unique avatar characteristics. Products are scanned into three-dimensional forms or turned into an avatar (Jeon 2022).

3.5 The Architecture of the Metaverse

Duan et al. (2021) presented the Metaverse design from a macro viewpoint, as illustrated in Fig. 3.5, including ecosystem, interaction, and infrastructure.

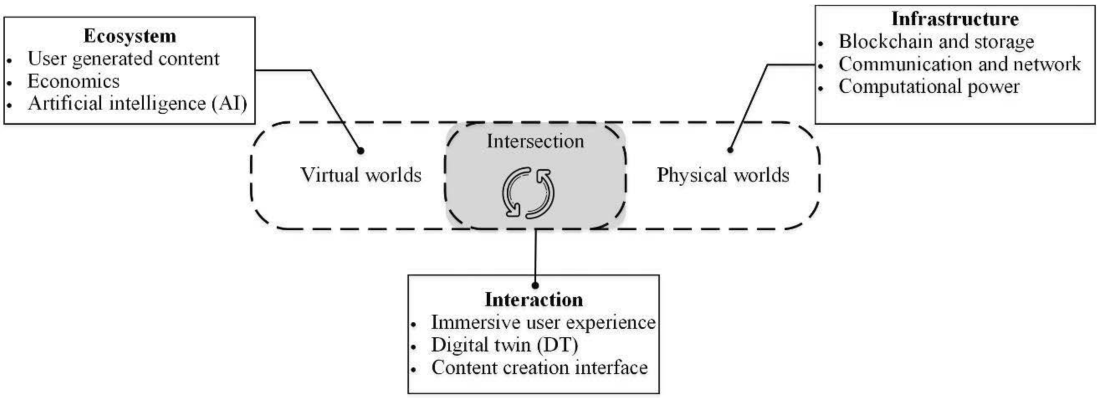

Figure 3.5: The Metaverse's three-layer architecture (Adapted from Duan et al. 2021).

3.5.1 Infrastructure

The infrastructure layer covers processing, communication, blockchain, and storage when operating a virtual environment.

Computation and communication. The metaverse's operation requires significant computational expenses. Communication technologies are important to support since the metaverse should be accessible everywhere. More focus is on how technological advancements in computing and communication might enhance the metaverse's user experience. How specialized computing equipment can be designed to accommodate the metaverse's massive computational usage, how cloud computing can be coordinated with mobile devices to improve the user experience on many terminals, and in the metaverse, the data format or encoding strategy to best transmit and transfer large-scale data are the open research issues for creating computers and communication for the metaverse:

Blockchain and storage. Everyone on the earth is projected to be connected through the metaverse. As a result, big data, maps, and roles will be produced and kept in mass storage. The blockchain must promote decentralization and fairness in the metaverse by facilitating sustainable ecosystem functioning (Berg et al. 2019, Cai et al. 2018). Advanced blockchain systems, such as Ethereum (Buterin 2014), contain a smart contract that might allow DApps to run, greatly increasing the blockchain's application reach and enabling the metaverse (Cai et al. 2018). It creates a decentralized social environment. Blockchain is based on a distributed ledger, it is considered an infrastructure component of the metaverse, and its complete application in the ecosystem layer will be offered. While developing the metaverse, how can the metaverse's massive data be effectively stored and retrieved, what consensus method should the blockchain use to sustain long-term economics, and how mass storage and blockchain can data be distributed and coordinated efficiently are the open research issues to be investigated.

3.5.2 Interaction

The interaction layer that links the actual and virtual worlds is a key component of the immersive user experience, DT, and content development.

Immersive user experience. Two major components must be addressed in user interactions and the metaverse to ensure an immersive user experience. First, data from the real world should be sent to the metaverse so that users may instruct their avatars to do the required actions. Also, real-time three-dimensional rendering technologies like virtual and augmented reality serve as the main interaction interfaces. On the other hand, current methods can only help in particular areas and cannot deliver a fully immersive user experience; hence how we can learn more about our users' preferences and improve our Metaverse interactions, and how we can mix input/output modalities during interactions to provide a comprehensive user experience are the current research problems arise.

Digital twins. Other things or creatures in the actual world may interfere with the virtual metaverse, portrayed as DTs in the simulated space (Essa 2000, El Saddik 2018). Ubiquitous sensing technologies may acquire physical device characteristics to keep them in the same state as their digital counterparts, and this is an interdisciplinary field that should include material science, signal processing, the IoT, and pattern recognition (Paulovich et al. 2018). On the other hand, virtual environment parameters may be returned to physical devices following the operation and processing in the metaverse. The DT generation in the metaverse is in its infancy and needs more investigation about how the physical environment linking to the metaverse should be represented as DTs, and how DTs in the metaverse might be more efficiently utilized to aid the real world.

Interface for creating content. The metaverse is an infinitely scalable and interoperable virtual world always evolving. The operators must construct the core components while users fill the universe with innovative user-generated content (UGC). Consequently, high-efficiency content creation is a crucial aspect of user-Metaverse interactions. 3D reconstruction approaches may be employed in the metaverse to generate DTs of buildings, objects, and environments in the real world (Ma and Liu 2018). 3D modeling software may be used to produce 3D models. On the other hand, these modeling methods depend on experience. How the physical properties of real-world things can be correctly replicated in the virtual world, and how existing interaction modes could be useful for content creation, experience, and functionality are the open research topics.

3.5.3 Ecosystem

The ecosystem may create a parallel living environment that continually benefits every one of the world's populations. Through actions like befriending AI-driven nonplayer individuals, people may have different social experiences than they would in the real world (NPC). UGC, economics, and AI are the three layers that make up the ecosystem layer.

Content created by users. User-generated content (UGC) is material that users develop instead of professionals or site management (Min et al. 2019). UGC in the metaverse is frequently variable and requires ownership (Krum et al. 2008). The blockchain-based NFT is an innovative mechanism for UGC by guaranteeing a digital value that is not interchangeable. UGC is preserved as an NFT on the blockchain. They also use smart contracts to trade them for liquidity. Although the UGCs may encourage individuals, it also poses many research questions about how more UGC based applications can be designed to promote the value of user-generated content, and how a fair mechanism can guarantee that UGCs are unique and prevent deliberate duplication.

Economics. Economic issues are critical in the metaverse's ecology, which may supply rich material and a vibrant community. The metaverse may experiment with new economic models thanks to a decentralized financial system built on smart contracts and the Fungible Token or FT. Existing successful alternatives, such as Uniswap and an Ethereum-based Decentralized Exchange or DEX, provide customers liquidity (Angeris et al. 2019). The auction of virtual items like land, rare things, valuable real estate, leasing, and prizes for accomplishing revenues from cryptocurrency investments are now the most important economic activity in the metaverse. Consequently, the metaverse generates a new kind of funding influenced by both real and virtual worlds. On the other hand, smart contract application development is subject to outside threats. The metaverse smart contract application development is vulnerable to external threats, and the metaverse fails decentralized financial services. As a result, how irreversible and long-lasting smart linkages could be utilized to ensure that the metaverse's economic system is secure, and how effective DeFi models can be created to increase NFT liquidity are the research questions to be formulated.

Artificial intelligence. According to the metaverse's core principle, advanced data analytics for analyzing, regulating, and NPCs are significant aspects of the metaverse. Planning-driven NPCs function as characters such as villains, companions, and plot support by posing challenges that offer aid and giving storyline support. Cutting-edge AI, deep learning (DL), and reinforcement learning (RL) are frequently used, leading to advancements in natural language processing (NLP) and computer vision (CV). How AI technology may enhance the metaverse's user experience by making it easier for users to operate and how AI technology can help NPCs comprehend and communicate more effectively are the research questions to be developed to give users an experience using NPCs.

3.6 Combined Digital Twins, AI, and Blockchain in Metaverse

According to Far and Rad (2022), the relationship between the DTs and the metaverse is depicted as a three-layer architecture supported by blockchain technology and a metaverse interface (see Fig. 3.6). As Yaqoob et al. (2020) state, a blockchain-based NFT is equal to DT and offers several advantages:

- DTs transactions offer immutability and transparency regarding the preceding premise, including purchasing, selling, or ownership transfer. As a result, they may be regarded to be safe against cyber-fraud.
- Since blockchain promotes autonomy, the outcomes of DTs cannot be tampered with by any authority or privileged insider. As a consequence, DT outputs based on the metaverse are trustworthy.
- Due to the decentralized governance of the metaverse, all authorized identities, including DTs, are legal since they are all recognized by a consensus process.
- Blockchain solves many security and resiliency concerns. Metaverse-based DTs are more dependable compared to centralized versions, and they are also more secure.
- Global DT traceability: Blockchain properties such as linking blocks, transparency, and immutability enable global DT and correspondence tracing.
- Product lifecycle management: Any Metaverse-based DT and its corresponding real-world product lifespan can be easily controlled.
- Communication between peers or P2P communications allows machine/user or machine/machine contact across DTs without the intermediate requirement.
- DTs data coordination and access credentials: Blockchain, as a Metaverse infrastructure, allows business coordinators to access DTs data readily.
- Metaverse's leading blockchain capabilities and user-friendly aspects are transparency and accountability for DTs data. Responsibility may

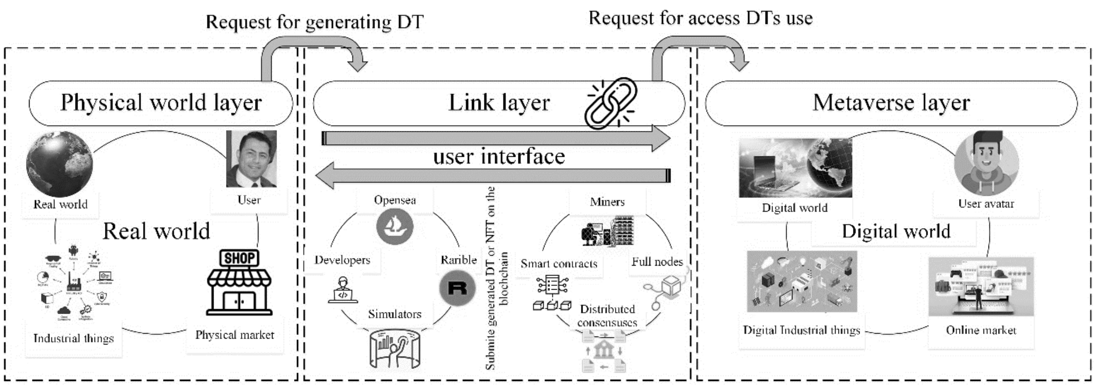

Figure 3.6: The three-layer design of the link between the physical world and the metaverse with the approach of applying DT in Metaverse (Adapted from Far and Rad 2022).

also aid in addressing regulatory issues regarding the legality and usage of DT.

- Decentralized Infrastructure: Metaverse offers DTs decentralized infrastructure that supports all blockchain features. As a result, using DTs in Metaverse is a safe and dependable option.

1. Layer of the Physical/Real World. Users and components in the real-world demand accurate DTs, which are, as previously noted, the best alternative for this need. As the name indicates, people, goods, and services (marketplaces, healthcare facilities, retail, and entertainment) are included in the physical/real-world layer. The requests are sent to the link layer, and the users pay costs referred to as the metaverse to connect to the digital world. DTs may be built on a vast globe, and the planet's largest DT is the world DT. Industrial and commercial DTs are the most common or relevant DTs. Furthermore, in the metaverse, individuals like to have incredibly accurate avatars. As a result, it encourages individuals to utilize DTs in Metaverse.

2. Link (User Interface) Layer. The layer of architecture which connects the real world to the metaverse, along with two sublayers as follows:

i) Simulation/Migration: The Link layer's first sublayer includes NFT generating services such as Opensea and Rarible. Computers such as 3D scanners and developers work together to produce digital representations of real-world items (DTs). Programmers and developers try to create exceptionally realistic and thorough DTs to transmit true experiences to real-world Metaverse users. Consequently, expert developers, affluent businesses, and sophisticated computers compete for new clients at this level. Following the development of the DT, the service/user pays for it by uploading it to the blockchain.

ii) Blockchain: Data, notably DTs, becomes accessible by DApps and other services after being submitted to the blockchain. Blockchain, which contains miners, smart contracts, blockchain nodes, and full nodes, is expected to be part of the Metaverse architecture. Blockchain tracks all Metaverse correspondences and transactions as a distributed ledger. Users in the metaverse may use the blockchain to submit new transactions or material and examine and utilize previously contributed information.

3. Metaverse as a Digital World Layer. The planned building's most attractive layer has a 3D digital environment (Metaverse). In this layer, DTs are combined with blockchain and smart contracts. In the metaverse layer, all people, services, and products may exist as DT or NFT, just as they do in the actual world. The digital world based on DT delivers people's avatars, retail marketplaces, manufacturing facilities, and all high-accuracy industrial items cost-effectively and remotely, digitally servicing the everyday needs of regular people and managers.

3.7 The Change of Business Model and Architecture Engineering and Construction (AEC) Vision in Metaverse

Clients in the conventional architectural and building sector will search for inventive architects, engineers, and contractors to engage in their projects to accomplish a task at the lowest possible cost and in the quickest possible time. Meanwhile, other AEC rivals' ideas will not be employed if they do not win the project contract (Gaffar 2021, Lee et al. 2021b).

Unlike the actual world, the metaverse offers a virtual metropolis full of possibilities. AEC provides several options to produce its unique digital design for everyone who wishes AEC to design art pieces such as architectural design and structural engineering items across the globe. A building project in the actual world takes at least 5 to 7 years from the design stage to the final delivery of the project. AEC provides various ideas, experiences, and technical contributions throughout the process. Thousands of design, structural, MEP, financial, and construction management restrictions are also resolved cooperatively by the AEC. Metaverse provides a platform for AEC to participate and collaborate to bring all knowledge from various disciplines together and virtually stimulate the project, which speeds up the overall coordination process in the digital world (Eno et al. 2009, Lee 2021b, Moneta 2020, Vlavianos and Nagakura 2021). The stimulated project may replicate multiple situations in the metaverse to test and validate other real-life characteristics, and the data gained helps enhance the project's originality, buildability, and sustainability in the actual world (Kit 2022). Unlike the traditional 3D model concept, NFT architecture can be more specifically and precisely described as a form of art even before it is built, allowing AEC to develop ideas that take their profession to new heights and create opportunities for

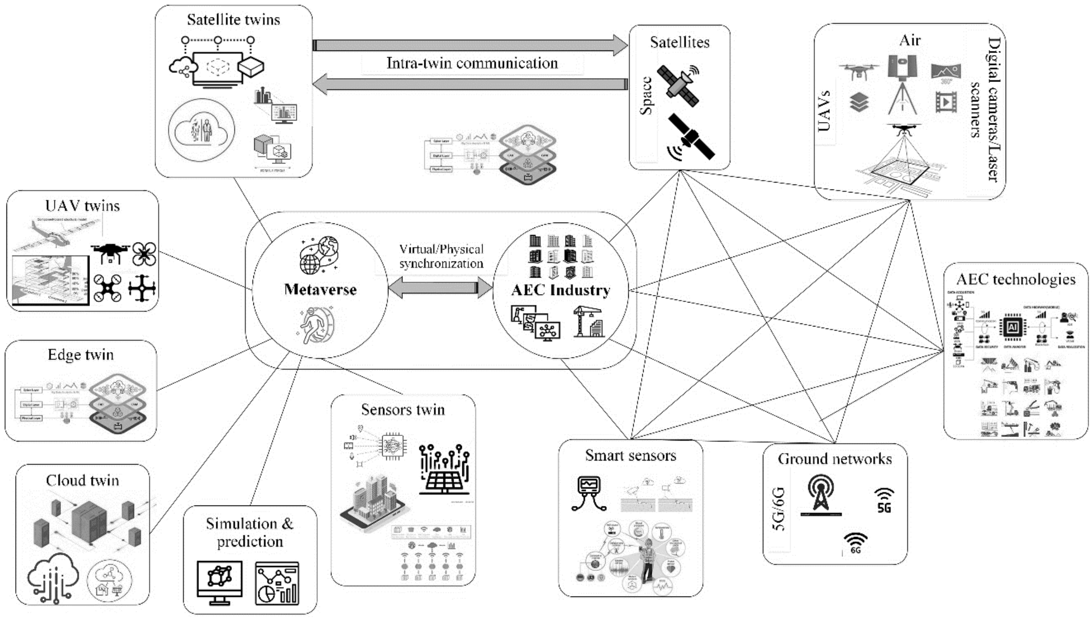

Figure 3.7: The AEC industry achieving real-time physical/virtual synchronization of the Metaverse and intelligent edge networks (Adapted from Xu et al. 2022).

AEC to produce and sell their digital version of the design in the digital economy.

With the growth of AI research, it was about the next-generation virtual world in the AEC business employing artificial intelligence. Users, for example, may use AI to train their avatars to do professional tasks in a virtual environment and Metaverse (Lee 2021b). The issue of labor resources, time, and cost in the actual world is readily substituted and compromised by deploying AI in the metaverse. A tough endeavor will take much work and time in the real world. However, employing AI avatars in the virtual environment and metaverse makes it possible to develop the task quickly and continuously for a long time.

Sensing and actuation need widespread edge devices and servers. The DT (Han et al. 2021) is one possible solution for virtual services, such as city twins and smart factory copies, to virtualize real-world edge networks to improve efficiency. By observing the DTs of edge devices and required infrastructures like UAVs, and space-air-ground integrated networks, users may quickly regulate their physical entities in the real world, which is critical to allocate resources efficiently in secure communications among physical and virtual components within mobile edge networks throughout physical and digital world synchronization to achieve seamless real-time immersion in the metaverse (Cheng et al. 2018, Cheng et al. 2019).

3.8 Challenges for Actualizing Metaverse

Digital twins, digital natives, and the metaverse are the three phases of moving from physical to virtual integration. Technological innovation and ecosystem-building efforts are required for our immersive future in the metaverse. Eternal, shared, contemporaneous, and three-dimensional, the limitless virtual-physical integrated cyberspace will be able to accommodate beyond those on earth. Even other planets may benefit from interplanetary transportation and communication (Alhilal et al. 2021).

Consequently, technology enablers and their technical demands have never been higher. The metaverse also emphasizes bringing virtual worlds together and demanding tasks in large-scale virtual environments. Thus, various socio-economic systems will arise in metacyberspace. Currency, commodity and capital markets, conventions, rules, cultures, and social characteristics are possible examples. Figure 3.8 displays a building and developing cyberspace during the following decade. Autonomous, permanent, united, and infinite cyberspace is made possible by technology enablers and ecosystem drivers. The fourteen major categories described in this chapter are interrelated; for example, Zhang et al. (2021) utilize IoT, network, CV, edge, XR, and user interaction in their design.

All disciplines should be approached holistically by researchers and practitioners. The metaverse, for example, must combine the virtual and real worlds, even if the virtual world is more accurate. It must rely on XR-driven immersive technologies (Lee et al. 2021a). Firstly, edge and cloud produce zero-latency virtual worlds. Secondly, as motion capture and gesture recognition, avatar and user engagement work seamlessly with XR. Thirdly, AI and computer vision are utilized to understand the metaverse and the production of DTs at scale. Finally, edge and AI work together to preserve privacy.

Extended Reality. Virtual worlds act as the metaverse's technical foundation, and it evolves from concept to reality, with VR/AR/MR as a crucial step. It is a virtual space where people can interact in a digital

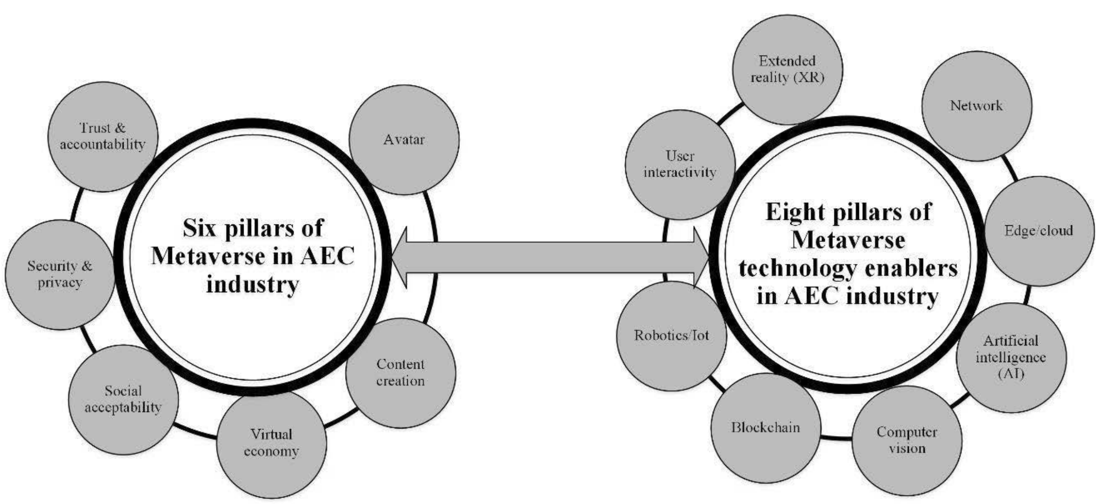

Figure 3.8: A plan for three-stage metaverse growth toward surreality (Adapted from Lee et al. 2021a).

setting. Users dwell in a world made of tangible virtual images as if they were in a parallel reality to ours. Such immersive technology will aid in developing the immersive internet of the future. For a realistic experience in the virtual networked world, the user uses VR to make the virtual world's functioning similar to that of the real world.

AR/MR, on the other hand, has the potential to alter the physical environment, which is becoming more intertwined with the metaverse. Digital entities migrating from virtual (VR) to real (MR) environments should get more design and technology attention. In principle, MR and the Metaverse allow virtual entities to integrate with the real world fully. Consequently, super-realistic virtual creatures combined with real-world surroundings will be shown on large displays, mobile headsets, or holography at any time and place. Users in the metaverse may interact and cooperate with real-world objects through digital entities. Consumers may use XR to access many technologies, including AI, computer vision, and IoT sensors (Lee et al. 2021a).

User Interactivity. Mobile user interaction methods, via the lens of XR, leads users to interact with digital overlays. Invisible computer interfaces allowing ubiquitous human involvement with virtual surroundings in the metaverse may be created through mobile processes that are developed in a body-centric, sensitive manner. Furthermore, multi-modal feedback signals, notably haptic feedback on mobile methods, let users interact with IoT devices and service robots in the metaverse with an improved sense of realism. Virtual worlds (VR/AR/MR), on the other hand, are augmented and complex, giving users a dreamy experience of certain feelings but lacking the ability to share and interact with other senses.

Brain-computer interface (BCI) technology links the human brain and numerous technological devices, enabling people to connect with them without language or limbs. Humanitarian sensations are produced by sending signals toward the brain, and BCI innovation may recreate all sensory experiences by activating the proper brain regions and using a BCI directly linked to the cerebral cortex. Neuralink66 is the best technology for connecting players to the virtual world in the posterity meta-universe age (Lee et al. 2021a).

Robotics and the Internet of Things. IoT devices use XR systems and autonomous automobiles to demonstrate their operations. Also, these systems let people join in decision-making and data management. Meanwhile, excellent XR interface designs will be used to make human-in-the-loop decisions. The user-centric design of immersive and virtual worlds through the design space of user interfaces with different forms of robotics, dark patterns of IoT and robotics, and nuanced controls of new robotic systems are still in their infancy.

Artificial Intelligence. AI, specifically deep learning, has progressed in Metaverse automation for designers, exceeding conventional methods. However, AI is not being used to expedite user operations and improve the immersive experience. Existing AI models are often highly complex and need significant computing power, incompatible with resource-constrained mobile devices. Consequently, it's necessary to create AI models that are both light and efficient.

Blockchain. Proof of work is the consensus process used by blockchain, which encourages users to spend time-solving puzzles regarding data security. Encryption data verification is a slower technique compared to the previous approaches. Consequently, an accelerated method is necessary to improve data scalability and access speed. Furthermore, all users access their data with public blockchains, raising privacy problems. Consequently, solutions for securing privacy in public blockchains may be investigated.

Computer Vision. Computer vision is the ability of computers to understand visual data about users' activities and surroundings. To develop a more trustworthy and realistic three-dimensional virtual world, computer vision algorithms must overcome many challenges. First, an interaction system must be able to grasp more complex settings, such as mixing virtual and real-world objects. Consequently, we expect the metaverse to deploy soon more accurate and computationally efficient spatial and scene understanding algorithms.

Furthermore, since the metaverse is so intertwined with the actual world and its inhabitants, more reliable body and location-tracking algorithms are required. Finally, for creating a realistic 3D environment and engaging with avatars in the metaverse, color correction, texture restoration, blur estimation, and super-resolution are essential. However, more flexible but efficient repair methods for the gap between actual and virtual content and the relationship with avatars should be researched (Lee et al. 2021a).

Edge and Cloud. For a seamless metaverse experience for the user, the last mile latency remains the primary latency bottleneck for both Wi-Fi and cellular networks, particularly for wirelessly connected mobile users. As a result, further edge service latency reduction is dependent on improvements in last-mile transmissions, such as the 1 ms promised by 5G. In addition, suppliers, service providers, and third parties are part of Multi-access edge computing (MEC). Consequently, many adversaries may be able to get access to MEC data and steal or tamper with important knowledge. In terms of security, even a small number of hacked edge devices in a distributed edge environment at various layers might disrupt the edge ecosystem and the metaverse services, such as a feature inference attack in federated learning if any client is compromised.

Network. The main network issues are related to conventional mobile network performance parameters, such as latency, throughput, and jitter, which are critical for a smooth user experience. User movement and embodied senses will add to the confusion. The metaverse will need a two-way connection within layers in contrast to the usual tiered network approach, where only little contact occurs between levels to meet the stringent user experience standards. The gNB will be able to broadcast network measurements to the user equipment connected through 5G and its predecessors, which may subsequently be delivered to the whole protocol stack up to the application to adjust content transport.

The transport layer, which handles congestion management, may send a congestion notification to the application layer. When such data is received, the application reduces requirements for the quantity of data sent to meet the application's throughput, bandwidth, and latency. In the same way, QoE measurements at the application layer are sent down to lower layers to improve content delivery and the user experience (Lee et al. 2021a).

Avatar. Users in virtual environments would rely on avatars as a digital representation to express themselves. The omnipresence of avatars with mobile sensors is inadequate for mobilizing our avatars, despite current technology's ability to record physical appearance features. Further research is required to increase the avatars' micro and nonverbal expressiveness.

It also reveals gaps in our understanding of the avatar design space, user perceptions such as alternating body ownership and super-realism, and their consequences on how avatars interact with a wide range of smart devices such as IoTs, intelligent autos, and robots. Avatar design might extend beyond human avatars. Consider the following scenarios: humans use pets as avatars, or humans and pets coexist and share their metaverse journey. The ethical design of avatars and associated online behaviors/representations would be a difficult task. The metaverse might provide a gray area for distributing undesirable concepts like prejudice, provoking debate, and encouraging a contemporary perspective on identity. In the metaverse, an avatar gives a separate identity to anyone, which may improve dialogue and stimulate new thoughts about human life. The computer clone or anyone's digital identity will live on even if your physical body is destroyed in the actual world (Lee et al. 2021a).

Content Creation. Content development is not only accessible to professional designers; everyone may do it in the metaverse. Different co-design methodologies like Participatory design might enable all Metaverse stakeholders to work together to develop the digital environment. Investigating motivations and incentives would allow the metaverse's content production to be accelerated via participatory design. It's uncertain how automated and decentralized censorship governance should be designed and implemented. Creating creative cultures with a wide range of cultural influences, cross-generational content, and the preservation of phased-out content such as digital heritage should also be considered.

Virtual Economy. The ambiguity in metaverse's currency is how much cryptocurrency can be relied upon to serve as cash and how much innovation is required to adapt it for virtual reality. In addition, since virtual users will be physical-world residents, the digital and real economies will be inextricably linked. Consequently, a holistic approach must be used while determining what the virtual economy means. Individual agent spending patterns in the virtual and real worlds and how economic activities in the two realms may interact are topics that should be investigated holistically. In addition, a virtual environment may be utilized as a virtual assessment tool to evaluate new economic policies before they are implemented in real life. The conversion mechanism optimizes the computer-mediated sandbox's configuration to properly reflect economic actors' motives to capitalize on such potential.

Social Acceptability. The behavior of metaverse users is depicted by social acceptability, which expresses collective assessments and views on acts and policies. Metaverse's long-term viability would decide on social acceptability concerning privacy threats, user diversity, justice, and addiction. Furthermore, appropriate regulations and standards must be implemented since the metaverse will impact both the actual and virtual worlds. On the other hand, it is believed that present societal acceptability norms may be applied. Manually matching such bits to the huge cyberspace, on the other hand, would be time-consuming and costly. Examining such elements on a case-by-case basis takes time as well. Hence autonomous agents in the metaverse rely on the automated adoption of rules.

Consequently, the scalability of such agents in the metaverse would become a major challenge. Procedures and instruments to prevent cybercrime and report abuse must be developed to increase the social acceptability of the huge internet (Lee et al. 2021a).

Security and Privacy. In terms of security, the increasingly digital-physical world will need constant verification of users' identities while accessing certain Metaverse applications and services, XR-mediated IoTs, and everyday mechanical objects. Furthermore, safeguarding the metaverse civilizations at scale requires preserving digital assets.

Requiring textual passwords for metaverse applications is a significant impediment to speeding up authentications along with many objects in these cases. The security specialists would look at establishing new ways for app authentication that use various modalities, such as biometric authentication based on muscle movements, body motions, and eye gazes. Our digital journey may include seamless identification in different physical situations, and this system must securely enhance accurate and fast detection.

The metaverse will store massive data on user behavior and interactions. Due to the accumulated data and traces, long-term privacy breaches would occur. Users will be overwhelmed by existing authorization forms when accessing every website with 2D UIs. Users of virtual 3D settings can't afford to regularly fill out so many authorization forms. Instead, machine learning must be developed to recognize user privacy choices in the metaverse's dynamic yet heterogeneous surroundings. Protecting users against digital copies is a great security issue while creating digital assets, such as avatars and twins. With 'deep-fake' avatars, these duplicates may modify users' metaverse behavior and reveal more sensitive information (Lee et al. 2021a).

Trust and Accountability. The metaverse, which merges XR with the internet, broadens the definition of biometrically inferred personal information. Privacy law cannot be used to define personal data because it cannot keep up with the speed of innovation. Providing a standard framework for categorizing personal data while being attentive to future changes would be a huge task. As human civilization advanced from the past to the future, minorities' rights were acknowledged. It's similar to how the internet's socio-technical systems formed in the early days when standards dictated what was and wasn't acceptable, and the democratic majority chose these norms. As the metaverse ecosystem evolves, minorities' and underprivileged communities' rights must be recognized. Potential abuse would have even more significant implications than typical socio-technical systems, with victims feeling abused as if they were in the real world.

3.9 Conclusion

Along with the inclusion of future technologies and the continual growth and refining of the ecosystem, digital twins will appear quite different in the coming years. Thanks to powerful computing devices and intelligent wearables, our digital future will be more interactive, living, embodied, and multidimensional. Many obstacles must be overcome before the metaverse can fully merge with the physical world and our daily lives. The metaverse, it is believed, will exist as a separate huge entity from our physical world. As a result, it is advocated for a comprehensive development plan.

AI and blockchain technologies play pivotal roles in the ever-expanding metaverse. Metaverse is a digital virtual environment that combines AI with blockchain technology to create a digital virtual environment where people may be incorporated into social/economic activities far beyond the physical world's bounds. Metaverse will speed up the application of cutting-edge AI and Blockchain technologies.

The fundamental components of each layer are described in-depth, as well as a list of promising study fields for each aspect. Infrastructure, interactivity, and ecosystem are all of the metaverse's three-layer design. The metaverse represents a human-centered computer vision that helps society in terms of accessibility, variety, equality, and humanism.

Academic and industry experts review comprehensively by assessing the most relevant works in metaverse components, digital currencies, virtual world AI technologies and applications, and blockchain-enabled technologies. It also anticipated major barriers and unsolved issues in building the metaverse's basic features via the marriage of AI and Blockchain. Academia and industry must collaborate to further exploitation and transdisciplinary research on the metaverse to establish an open, fair, and rational future metaverse.

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