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Examining the Technical Aspects of Blockchain for the Metaverse: A Review

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Abstract

Since 2021, social networks and virtual worlds have seen a major increase in popularity of the metaverse idea. With the use of numerous technologies, the metaverse promises to transform user experiences by offering individualized and immersive 3D settings. The question of how to safeguard the digital information and data of metaverse users arises among all the excitement and benefits. In this regard, blockchain technology appears as a possible answer, offering distinctive properties like decentralization, immutability, and transparency. To better comprehend the function of blockchain in the metaverse. In order to explain the rationale for using blockchain for this purpose, our study begins by introducing the metaverse and blockchain. We dig into the different applications of blockchain. For each aspect, we explore the metaverse technical challenges that are associated with it and highlight how blockchain can address them effectively In conclusion, we outline promising directions that can drive further research, innovation, and development toward the integration of blockchain technology in the metaverse. We aim to pave the way for a future where blockchain plays a crucial role in enhancing the metaverse experience and ensuring the security and integrity of users' digital assets and data.

Keywords: metaverse, blockchain technology, digital assets, interoperability, governance, identity, virtual economies, intellectual property, transparency, social tokens, security, data integrity.

I. Introduction

In the ever-evolving landscape of technology and virtual reality, the concept of the metaverse has captured the imagination of millions around the world. It's a term that has gained momentum, representing a digital realm where individuals can immerse themselves in a virtually constructed universe, interacting with others and exploring boundless possibilities.

The metaverse represents a step forward in human connection, transcending physical limitations and enabling a new level

of social interaction. Imagine a place where distance doesn't matter, where you can meet and engage with people from different corners of the globe, sharing experiences and forging meaningful connections. It's a virtual space that blurs the lines between the real and the digital, where our avatars become extensions of ourselves, allowing us to express our creativity and individuality in ways we never thought possible. [1]

The Metaverse offers a world full of exciting possibilities. It's like a vast playground where you can explore new frontiers, wander through fantastical landscapes, and dive into art and culture. Within this digital realm, you'll find virtual museums, concerts, collaborative workspaces, and educational hubs, all waiting for you to discover. It's a place where personal growth, entertainment, and learning opportunities abound [2]. However, as we embrace this digital frontier, concerns naturally crop up. Privacy, security, and identity become top priorities. Safeguarding your personal information becomes crucial, and maintaining trust and authenticity becomes essential because, in this realm, it's easy for anyone to create a false identity. These challenges need our attention as we navigate this expanding virtual universe [2]. The Metaverse signifies an extraordinary opportunity for human progress, where the merging of imagination and technology knows no bounds. It invites us to dream big, envisioning a future where the digital and the real seamlessly intertwine, enriching our lives and shaping the course of human evolution [3]. Blockchain technology has captured the world's attention in recent years for a good reason. At its core, blockchain is a revolutionary concept, a decentralized and transparent system that ensures secure and unchangeable transactions. It's like a digital ledger, meticulously recording every transaction ever made, creating an unbreakable chain of blocks [4].

Integrating blockchain technology into the Metaverse holds immense promise for revolutionizing how we interact, transact, and build digital experiences. The Metaverse, a virtual realm where people can immerse themselves in interconnected virtual worlds, can greatly benefit from the transparency, security, and decentralization offered by blockchain [5]. One significant advantage of employing blockchain in the Metaverse is the establishment of secure and verifiable digital ownership. Through the use of non-fungible tokens (NFTs) on a blockchain, users can assert ownership over virtual assets such as land, avatars, or virtual items. This not only grants users full control over their digital belongings but also enables the creation of thriving virtual economies where confident buying, selling, and trading of assets can occur [6].

The incorporation of blockchain also fosters interoperability between various Metaverse platforms. Presently, each virtual world operates in its own closed ecosystem, restricting the transfer of assets and experiences across different platforms. However, with blockchain technology, users can effortlessly transfer their digital assets from one Metaverse to another, expanding the horizons for cross-platform interactions and experiences. This newfound interoperability promotes creativity, innovation, and collaboration on a grander scale, resulting in a more vibrant and interconnected Metaverse. However, challenges still exist in fully realizing the potential of blockchain in the metaverse. Scalability, energy consumption, and user experience are areas that require further development and refinement. As technology advances, these obstacles can be overcome, leading to a metaverse where blockchain becomes an integral part of the infrastructure, enabling a new era of digital interaction and expression. [7]

Many surveys and overviews conducted to show the impact of employing blockchain within the metaverse.

The survey commences by discussing the trends, characteristics, and architecture of the metaverse. It then presents an overview of existing research on blockchain, networking, and the integration of these technologies, encompassing their applications, challenges, and general concepts. Additionally, it provides a summary of the diverse applications of the metaverse, underscoring its significance and potential for development across various fields. Lastly, it explores the open issues, challenges, and future research directions necessary to fully unlock the metaverse's potential [8]. In their study cited as [9], the authors introduce blockchain and the metaverse, shedding light on the motivations behind adopting blockchain technology in this context. They subsequently delve into a detailed examination of the technical aspects of employing blockchain in the metaverse. This includes exploring data acquisition, storage, sharing, interoperability, and privacy preservation, addressing the technical challenges specific to the metaverse and illustrating how blockchain can offer potential solutions. Furthermore, they investigate the impact of blockchain on key enabling technologies within the metaverse, such as the Internet of Things (IoT), digital twins, multi-sensory and immersive applications, artificial intelligence, and big data. The authors also showcase notable projects that exemplify the role of blockchain in metaverse applications and services [9]. The survey also explores the intersection of blockchain, artificial intelligence (AI), and the metaverse [10]. It examines the latest research on metaverse components, digital currencies, AI applications in the virtual world, and blockchain-powered technologies. The authors emphasize the importance of collaboration between academia and industries to advance the fusion of AI and blockchain in the metaverse. They hope that their survey can assist researchers, engineers, and educators in shaping an inclusive, fair, and rational future for the metaverse [10].

II. Blockchain technology

The origins of blockchain can be attributed to the enigmatic individual known as Satoshi Nakamoto. Back in 2008, Nakamoto authored a whitepaper titled "Bitcoin: A Peer-to-Peer Electronic Cash System," which introduced the world to the concept of blockchain technology. The primary objective behind blockchain was to establish a decentralized and transparent system for recording and verifying transactions, eliminating the need for intermediaries like banks.

Think of a blockchain as a digital ledger, kind of like an ultra-secure digital notebook. This special notebook is designed to record transactions and protect them from any sneaky changes or cheats.

Now, what makes it unique is that instead of being controlled by one big boss, like traditional databases, it operates on a network of computers, each called a "node." These nodes are like guardians, and each one keeps a copy of the entire notebook. This way, no single person or organization can boss it around [11].

When someone makes a transaction, it's like sending a message to this network of guardian nodes. These nodes don't just accept the message blindly; they put on their detective hats. They have to solve tricky puzzles, like solving riddles, to make sure the transaction is genuine and legitimate. This whole process is known as "mining." It's like a big digital treasure hunt where the goal is to verify and secure transactions. Once a transaction is verified, it joins other transactions to create a new block of data. Each block is assigned a unique identifier, called a hash, generated using a cryptographic algorithm. Additionally, the hash of each block incorporates the hash of the preceding block, forming a chain-like structure

that links all the blocks together, hence the term "blockchain." The decentralized nature of blockchain ensures that no single entity can modify or manipulate the data stored in the ledger. If anyone attempts to tamper with a block, it will alter the hash value, thereby rendering subsequent blocks invalid. Consequently, this makes it exceedingly challenging for hackers or malicious actors to meddle with the transaction history.

Moreover, the transparency of blockchain allows anyone to access the complete transaction history, fostering trust and accountability. However, while the transaction details are visible, the identities of the participants are typically anonymous, thereby ensuring a certain degree of privacy [12].

III. Metaverse

The concept of the metaverse has captured the imagination of millions around the world, the metaverse is a virtual reality space that transcends individual platforms or experiences. It's a fully immersive digital universe where users can interact with each other and the environment, blurring the lines between the physical and the digital realms. Imagine a world where you can explore stunning landscapes, attend virtual events, create art, conduct business, and even socialize with friends—all without leaving the comfort of your home[13].

The concept of the metaverse originally emerged from the world of science fiction literature and movies. Think about stories like Neal Stephenson's "Snow Crash" and the blockbuster film "The Matrix." They envisioned vast digital realms where individuals could escape their ordinary lives and immerse themselves in entirely different worlds. These early ideas ignited the creativity of tech enthusiasts and forward-thinkers, paving the way for what we now recognize as the metaverse.

Furthermore, the COVID-19 pandemic made the metaverse even more appealing. With people confined to their homes, there was a growing need for new ways to connect, work, and have fun. Virtual meetings, conferences, and concerts gained popularity, revealing that standard video calls were no longer sufficient. This shift in our interaction with technology heightened the demand for a more immersive digital realm, which is precisely where the metaverse fits in. [14]

The metaverse embodies a vision of a fully immersive digital universe that surpasses the boundaries of individual platforms. Its rise in popularity can be attributed to its roots in science fiction, advancements in virtual reality (VR) and augmented reality (AR) technologies, the ascent of online gaming, and the impact of the COVID-19 pandemic. As the metaverse continues to evolve, it has the potential to reshape our lifestyle, work dynamics, and social interactions in the digital era [15].

IV. Blockchain and metaverse

Blockchain is an incredible technology that has the power to revolutionize how we carry out transactions and exchange information. On the other hand, the concept of the Metaverse paints a picture of an alternative reality or virtual universe where people can connect, build, and engage in various activities. Imagine it as an enormous interconnected digital world

that encompasses diverse digital spaces, platforms, and experiences. By blending elements of virtual reality, augmented reality, and the internet, the Metaverse offers an immersive and interactive setting that blurs the lines between the physical and digital realms.

When we think about the development of the Metaverse, blockchain technology can play a pivotal role by providing a secure and transparent foundation. With blockchain, the ownership and transactions of digital assets within the Metaverse can be reliably tracked, verified, and protected. As a result, users can enjoy true ownership of their virtual assets, like virtual real estate, digital artwork, or in-game items, without having to rely on centralized platforms. The decentralized nature of blockchain ensures that control and the value of these assets aren't subject to the arbitrary decisions of a single authority.

Moreover, blockchain can facilitate the creation of decentralized applications (DApps) within the Metaverse. These DApps can offer a wide range of services, including virtual marketplaces, social networks, gaming platforms, and even governance systems. By harnessing blockchain technology, these DApps can deliver heightened security, transparency, and trust to users, fostering a more inclusive and equitable experience within the Metaverse.

Table (1) shows the Technical Aspects of Blockchain for the Metaverse

Table 1. The Technical Aspects of Blockchain for the Metaverse

Use Case	Description	Example
Digital Assets	Blockchain can enable ownership and provenance of digital assets within the metaverse, allowing users to buy, sell, and trade unique items, virtual land, and in-game assets.	Example: CryptoKitties, a blockchain-based game where users can buy, sell, and breed unique virtual cats.
Interoperability	Blockchain can facilitate interoperability between different metaverse platforms, allowing users to transfer assets and identities seamlessly across various virtual worlds.	Example: Decentraland, a blockchain-based virtual world where users can create and trade virtual assets and land.
Governance	Blockchain-based governance models can be implemented in the metaverse, enabling decentralized decision-making, voting systems, and community-driven management of virtual environments.	Example: The Sandbox, a blockchain-powered virtual world that allows community members to participate in governance decisions and contribute to the platform's development.
Identity	Decentralized identities (DIDs) based on blockchain technology can offer users distinct, self-governed identities within the metaverse. This guarantees privacy, security, and the ability to seamlessly navigate various platforms and experiences.	Example: uPort, a blockchain-based identity system that enables users to have control over their digital identities and selectively share personal information.
Virtual Economies	Blockchain empowers the establishment of virtual economies within the metaverse, enabling users to earn, trade, and exchange virtual currencies and tokens. This fosters economic interactions and creates new opportunities within this digital realm.	Example: Axie Infinity, a blockchain-based game where players can earn and trade in-game tokens by battling and breeding virtual creatures called Axies.
Intellectual Property	Blockchain can contribute to safeguarding intellectual property rights within the metaverse by creating unalterable records of ownership, licensing, and content creation. This, in turn, promotes trust and proper attribution for creators.	Example: SuperRare, a blockchain marketplace where artists can sell and authenticate their digital artworks as non-fungible tokens (NFTs).
Transparency	Blockchain's transparent and auditable characteristics bolster trust in the metaverse by enabling users to validate transactions, confirm scarcity, and trace the history of assets and virtual experiences.	Example: OpenSea, a blockchain marketplace where users can buy, sell, and trade various digital assets, including NFTs, with full transaction visibility.
Social Tokens	Blockchain-powered social tokens have the potential to be employed in the metaverse, enabling creators, influencers, and communities to monetize their content, connect with their fans, and cultivate dynamic economies centered on their virtual presence.	For instance, Roll, a blockchain platform, facilitates creators and influencers in launching their personalized social tokens, which in turn nurtures direct interactions and the exchange of value with their communities.

1. Digital Assets

Digital assets encompass a wide array of content and value stored in digital form, ranging from images, videos, music, and documents to cryptocurrencies like Bitcoin. In our increasingly digital-centric society, these assets play a fundamental role in shaping how we interact with information and how we create and consume it. One of the defining features of digital assets is their ease of creation and distribution. With just a few clicks, anyone can capture a photo, record a video, or compose music. The digital format allows for quick and straightforward duplication, enabling individuals to instantly share their creations with a global audience. This accessibility has opened up new avenues for self-expression and creativity, empowering individuals to showcase their talents and perspectives on various platforms.

Furthermore, digital assets have brought about significant transformations in industries such as entertainment and media. Streaming platforms have become commonplace, granting us access to vast libraries of movies, TV shows, and music with a simple internet connection. Artists no longer depend on traditional distribution channels to reach a global audience, while consumers enjoy the convenience and flexibility of accessing content at their convenience. Another substantial category of digital assets revolves around cryptocurrencies and blockchain technology. Cryptocurrencies like Bitcoin and Ethereum are decentralized digital currencies that use cryptographic techniques to secure transactions and regulate the creation of new units. These digital currencies have gained prominence for their potential to disrupt traditional financial

systems, offering alternatives to conventional banking and facilitating peer-to-peer transactions on a global scale. Blockchain technology, serving as the foundational framework for cryptocurrencies, is a decentralized and transparent digital ledger. It ensures secure and tamper-resistant record-keeping, providing a means to verify the authenticity and ownership of digital assets. Beyond cryptocurrencies, this technology finds applications in areas such as supply chain management and voting systems, holding the promise of transforming various industries. Despite the numerous advantages of digital assets, concerns regarding privacy, security, and intellectual property rights have emerged. The ease of copying and sharing digital content has led to issues like copyright infringement and unauthorized distribution. Additionally, safeguarding the security of digital assets is of utmost importance, as cyberattacks and hacking attempts pose significant risks to individuals and organizations alike. digital assets have fundamentally reshaped how we create, consume, and exchange value in the digital era. They have democratized creativity, revolutionized industries, and unleashed new possibilities for innovation. However, it is crucial to navigate this digital landscape responsibly, addressing the challenges that come with it and ensuring the protection of privacy, security, and intellectual property rights.

Table (2) shows the latest research on Digital assets within the blockchain and metaverse

Table 2. Latest research on Digital assets within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[16]	Data-driven consumer engagement, virtual immersive shopping experiences, and blockchain-based digital assets in the retail metaverse	Quantitative literature review using databases and assessment tools	Clarifies the potential of predictive analytics, AI, navigation tools, computer vision, and cognitive enhancement in configuring customized shopping experiences in the retail metaverse
[17]	Transparent sales mechanism for digital assets using smart contracts and blockchain	Proposal of using smart contracts in the public blockchain, IPFS for file distribution, ERC-721 for ownership, and ECC for security	Use of Ethereum smart contract, IPFS, ERC-721, and ECC to create a transparent system for distributing and securing digital assets, ensuring fair distribution of royalties to creators
[18]	Immersive virtual shopping experiences in the retail metaverse	Quantitative literature review using databases and assessment tools	Live streaming e-commerce can leverage consumer retail data and deep learning algorithms to enhance real-time customization, optimize shopping experiences, increase user engagement, and drive operational efficiencies
[19]	Potential challenges and vulnerabilities of the digital asset ecosystem	Analysis using the Federal Reserve's framework for analyzing vulnerabilities	The digital asset ecosystem has grown rapidly but exhibits limited interconnections with the traditional financial system, presenting emerging vulnerabilities that could pose risks to financial stability if the ecosystem becomes more systemic
[20]	Blockchain-based ID management system for IoT ecosystem	Proposal of a blockchain-based system for secure ID management in IoT ecosystem	Blockchain technology can address security and privacy challenges in ID management systems, particularly in IoT ecosystems, by offering self-sovereign identity, cryptography, and data provenance.

2. Social Tokens

The advent of blockchain technology has truly revolutionized how we think about digital assets and our interactions with them. It's a cutting-edge, decentralized system that ensures secure transactions and accurate record-keeping. However, what really captures our imagination is its application in the world of social tokens. Social tokens act as digital representations of individuals, brands, or communities. They can be generated and distributed through a blockchain platform, which gives them unique qualities and abilities. These tokens play a pivotal role in fostering community

participation, rewarding loyal supporters, and enabling innovative ways of exchanging value within online communities.

One of the primary advantages of using blockchain for social tokens is the establishment of trust and transparency. Blockchain's decentralized nature ensures that transactions and ownership records are securely stored and accessible for verification by anyone on the network. This effectively safeguards against fraudulent activities and ensures the enduring value of the token. Furthermore, blockchain technology enables programmability and the integration of smart contracts. This means that social tokens can have specific rules and conditions, allowing for a wide range of creative applications. For instance, they can provide exclusive access to content or events, incentivize engagement within a community, or even be traded on decentralized exchanges. In recent years, social tokens have gained immense popularity, especially among content creators, influencers, and online communities. These tokens offer creators a fresh way to monetize their work and engage with their audience. Supporters of creators or communities can acquire social tokens, which can then be used to access special perks or services offered by the creator. This creates a more direct and personalized connection between creators and their fans. However, it's important to acknowledge that the realm of social tokens is still relatively new and constantly evolving. Regulatory frameworks are still being developed, and there are inherent risks associated with investing in or trading social tokens. As with any investment or financial transaction, conducting thorough research and exercising caution is imperative. To conclude, the advent of blockchain technology has unlocked thrilling possibilities for the development and utilization of social tokens. These tokens provide a means to deepen community engagement, reward supporters, and establish new economic models within online communities. Although the landscape is continuously evolving, social tokens possess the potential to redefine how we interact with content creators and online communities in the digital era.

Table (3) shows the latest research on Social Tokens within the blockchain and metaverse

Table 3. Latest research on Social Tokens within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[21]	Data-driven consumer engagement, virtual immersive shopping experiences, and blockchain-based digital assets in the retail metaverse	Literature review and data analysis	Predictive analytics can enhance customized experiences in virtual environments
[22]	Use of smart contracts and blockchain for transparent sales of digital assets	Proposal and discussion	Proposed method can secure the link to digital assets and protect intellectual property
[23]	Immersive virtual shopping experiences, consumer-driven e-commerce, blockchain-based digital assets, and data visualization tools	Literature review and data analysis	Livestreaming e-commerce and deep learning algorithms can enhance customization and user engagement
[24]	Examination of potential challenges to financial stability arising from the digital asset ecosystem	Analysis based on the Federal Reserve's framework	Digital asset ecosystem has limited spillovers to traditional financial system, but emerging vulnerabilities should be considered
[25]	Blockchain-based ID management system for IoT ecosystems with a focus on data provenance of digital assets	Proposal, design, and development of a proof-of-concept prototype	Blockchain can address security and privacy issues in ID management systems for IoT ecosystems

3. Interoperability

Blockchain interoperability refers to making different blockchain networks work together seamlessly. Think of it like

creating a common language or a bridge that allows these independent blockchains to securely and efficiently exchange information, assets, and transactions. Picture a world with multiple blockchains, each having its own rules, protocols, and functions. While these blockchains are meant to be decentralized and unchangeable, they often operate separately, limiting their potential and slowing down widespread adoption. Interoperability aims to solve these problems by connecting them and enabling data and value to flow across them.

One of the main challenges in achieving blockchain interoperability is the absence of standard protocols and communication methods. Each blockchain network might use different ways to reach agreements, organize data, or create smart contracts, making it hard for them to understand and work with each other. To address this, various projects and initiatives have emerged, offering solutions that help different blockchains communicate. These solutions use different methods to enable this communication. Some projects focus on building bridges or gateways that allow assets to move between different blockchains. Others suggest using sidechains or off-chain protocols that create middle layers for interoperability. There are also efforts to create universal standards and protocols that multiple blockchains can adopt to ensure they work well together.

Blockchain interoperability has great potential. It can give decentralized applications (dApps) access to data and services from different blockchains, making them more versatile and valuable. It can also simplify moving digital assets between blockchains, without relying on centralized exchanges. Additionally, interoperability can encourage collaboration and innovation by letting developers combine the strengths of different blockchains. They can use the security and immutability of one blockchain while benefiting from the scalability and speed of another. This can lead to creating more powerful and adaptable blockchain ecosystems that serve a wide range of industries.

However, achieving widespread blockchain interoperability comes with challenges. Besides technical issues, there are also concerns about governance, security, and regulation that need to be addressed. Developing standard protocols, ensuring trust and security in cross-chain transactions, and navigating legal and regulatory aspects are crucial steps in realizing the full potential of blockchain interoperability.

Table (4) shows the latest researches on interoperability within the blockchain and metaverse

Table 4. Latest researches on interoperability within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[26]	Interchain interoperability and atomic cross-chain transactions in the blockchain ecosystem	Systematic literature review	Atomic swap can enable instant token transfer and facilitate a sustainable payment system
[27]	Interoperability of electronic health records (EHRs) using blockchain	Systematic review	Various blockchain-based solutions for EHR interoperability
[28]	Blockchain technology and AI-based decentralized access control model for secure healthcare interoperability	Proposal and implementation using Ethereum blockchain	Decentralized model enables secure data exchange in healthcare
[29]	Interoperability of blockchains in the context of supply chain systems	Analysis of different interoperability approaches and a layered model	Identifies various interoperability approaches and research gaps
[30]	Blockchain interoperability solution based on publish-subscribe architecture for data sharing	Proposal and integration with Hyperledger Indy, Aries, and Ursa stack projects	Integration of decentralized identity services for secure data sharing

4. Governance

Blockchain governance refers to the manner in which choices are determined and regulations are put in place within a blockchain network. It resembles the system of checks and balances we have in our society to ensure fairness and order. In a blockchain, governance is of utmost importance as it dictates the functioning, development, and resolution of conflicts within the network. Unlike conventional centralized systems where a single authority wields power, blockchain governance is often decentralized. It involves a network of participants, often referred to as nodes or validators, who collectively make decisions.

Blockchain governance involves individuals or organizations with a vested interest in the blockchain network. One prevalent method of blockchain governance is called on-chain governance. In this system, decisions are made using smart contracts or protocol updates, with network participants casting votes. Voting can occur through various methods, like stake-weighted voting or one vote per participant. The goal is to achieve consensus among participants on proposed changes or decisions. Another approach is off-chain governance, where decisions are made outside the blockchain. This can involve discussions and debates among participants in forums, mailing lists, or other communication channels. While the final decision may eventually be implemented on the blockchain, the governance process occurs off-chain.

The primary objective of blockchain governance is to ensure the network's security, resilience, and adaptability to changing circumstances. It involves finding a balance between decentralization, where power is distributed among many participants, and efficiency, where decisions can be made promptly. Effective blockchain governance requires transparency, accountability, and inclusivity. Transparency ensures that decisions and the reasoning behind them are visible to all participants, reducing the risk of manipulation or corruption. Accountability holds participants responsible for their actions and decisions, ensuring they act in the network's best interest. Inclusivity means that all participants have a voice and can participate in the decision-making process, regardless of their stake or influence.

Blockchain governance is a continuously evolving field, and different blockchain networks may adopt various models or combinations of on-chain and off-chain governance. The aim is to find the most effective approach to governing the network while upholding the core principles of decentralization, security, and consensus.

Table (5) shows the latest researches on governance within the blockchain and metaverse

Table 5. The latest researches on governance within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[31]	Decentralized governance systems and the integration of blockchain technology and smart contracts	Systematic literature review following PRISMA guidelines	Identifying core outcomes and correlations related to smart urban governance
[32]	Role of blockchain technology in building a trustworthy and collaborative environment in SME clusters	Development of a blockchain commons governance framework based on qualitative analysis	Examining the dimensions of blockchain commons governance and its role in supporting SME clusters
[33]	Self-sovereign identities (SSIs) based on blockchain and their impact on information sharing and governance	Exploration of blockchain-based SSIs and assessment of their impact on data storage and governance	Emphasizing the importance of regulation and a combination of centralized and decentralized governance in the digital society
[34]	Overcoming barriers in the adoption of blockchain applications in supply chain through collaborative efforts	Multiple case study methodology comparing collaborative blockchain applications	Combination of centralised management and decentralised oversight is crucial for successful blockchain application development
[35]	Blockchain-based governance model for COVID-19 digital health certificates in the EU	Framework development to assess the viability of blockchain as a governance model for COVID-19 digital health certificates	Legal compliance, risks, and ethical implications remain unresolved with the use of blockchain for governance

5. Blockchain-based decentralized identities

Decentralized identities offer a remarkable approach to safeguarding personal information, relying on the foundation of blockchain technology. Unlike traditional methods that rely on a single authority to authenticate identity, decentralized identities utilize a network of computers to collectively validate information. This approach ensures that no single entity or organization holds complete control over your identity, significantly minimizing the risk of data breaches and identity theft. The true beauty of decentralized identities lies in the principle of self-sovereignty. You gain the freedom to choose which information to share, with whom, and for how long. You have the power to disclose specific attributes about yourself without revealing your entire identity. For instance, if you need to prove that you're above 18 to access certain services, you can simply share that particular piece of information without divulging your birthdate or other personal details. Furthermore, decentralized identities extend beyond individuals alone. They can also be embraced by organizations and even Internet of Things (IoT) devices. Just imagine a world where your smart home devices possess their own unique identities and can securely interact with other devices or services without relying on a central authority to facilitate communication. This level of autonomy and security holds immense potential to transform industries such as finance, healthcare, and supply chain management. Of course, as with any new technology, decentralized identities face their own share of challenges. Safeguarding privacy, achieving interoperability across different platforms, and addressing scalability concerns are some of the obstacles that must be overcome. However, the potential benefits in terms of privacy, security, and user control make decentralized identities an exhilarating field of development. Blockchain-based decentralized identities empower individuals, organizations, and even devices to take charge of their own identities and confidently manage their personal information. By harnessing the transparency and security offered by blockchain technology, decentralized identities have the ability to reshape how we authenticate ourselves and interact with the digital realm. It's an exciting concept that brings us one step closer to a more secure and user-centric online ecosystem. Table (6) shows

the latest research on Blockchain-based decentralized identities within the blockchain and metaverse

Table 6. The latest research on Blockchain-based decentralized identities within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[36]	Decentralized and lightweight anonymous FL identity authentication scheme (DAFL)	Design of a decentralized storage FL authentication framework and lightweight digital signature algorithm	Lower authentication overhead and better convergence performance compared to existing schemes and vanilla FL systems
[37]	Decentralized identifiers (DIDs) and verifiable credentials (VCs) for EHR authentication	Blockchain-based framework with DIDs and VCs for patient authentication and consent management in EHRs	Improved entity authentication in a decentralized manner, enabling privacy, interoperability, and consent management in EHR systems
[38]	Trust management for blockchain-based self-sovereign identity management (SSI)	Literature review and survey of trust requirements and state-of-the-art blockchain technology for SSI	Identification of research gaps and opportunities for enhancing security, privacy, and trust management in blockchain-based SSI systems
[39]	Blockchain-based identity management and access control (BIMAC) for open banking (OB)	Development of a BIMAC framework for integrating digital identity, data sharing, and privacy preservation in OB	Improved trust, privacy, and security in OB ecosystem through decentralized identity management, data authorization, and access control
[40]	Assessment of self-sovereign identity (SSI) solutions for a blockchain-based land registry	Systematic literature review evaluating existing SSI solutions and their compliance with SSI principles in land registry	Identification of limitations in existing digital identity solutions and the potential of SSI in providing a secure and efficient identity solution in land registry systems

6. Virtual Economies

Blockchain functions as a digital ledger that meticulously records transactions. Unlike traditional systems, it operates in a decentralized manner, devoid of any central authority overseeing everything. Instead, a network of computers collaborates to validate and document transactions. This unique setup enhances security and fosters transparency. This is where the significance of blockchain becomes apparent. By leveraging blockchain, virtual economies can establish a foundation of trust and ownership. Every transaction and transfer of ownership can be meticulously logged on the blockchain, generating an open and unalterable record. Consequently, when you purchase something within a virtual realm, it becomes intricately linked to your digital identity. It remains securely in your possession, impervious to tampering, and leaving behind an indelible trail. Additionally, blockchain empowers the implementation of "smart contracts" in virtual economies. These contracts are akin to self-executing agreements that automatically enforce predefined terms and conditions. Consider a scenario where you wish to sell a virtual item, stipulating that it can only be utilized for a limited duration. Through a smart contract, the item would promptly vanish or become unusable as soon as the designated time expires. Such functionality introduces a new level of reliability and automation to virtual economies. Moreover, blockchain facilitates the creation and management of distinctive digital assets known as non-fungible tokens (NFTs). These tokens possess unique characteristics and serve as representations of ownership for digital items, including virtual land, rare collectibles, and even digital artwork. Blockchain platforms provide avenues for buying, selling, and trading these NFTs, thereby opening up a novel market for enthusiasts of virtual economies. In the realm of buying and selling virtual goods, blockchain technology is causing a stir by instilling transparency, security, and trust. Observing how this technology shapes our interactions within virtual realms and online games is genuinely captivating. Table (7) shows the latest research on Virtual Economies within the blockchain and metaverse

Table 7. The latest research on Virtual Economies within the blockchain and metaverse

Abstract	Key Focus	Methodology	Findings
[41]	Retail business analytics for customer behavior in blockchain-based metaverse platforms	Quantitative literature review of databases and elimination criteria for article selection	Optimization of purchase journeys and personalized shopping experiences using customer behavior analytics in immersive virtual environments
[42]	Optimization of customer engagement in metaverse live shopping	Quantitative literature review of databases and elimination criteria for article selection	Attainment of personalized digital shopping experiences through customer engagement tools in immersive virtual spaces
[43]	Spatial awareness and tracking tools for immersive shopping experiences in the metaverse economy	Quantitative literature review of databases and elimination criteria for article selection	Enablement of immersive shopping experiences and shaping of customer preferences through spatial awareness and tracking tools
[44]	Virtual closed-loop supply chain framework using blockchain and IoT technologies	Development of a mixed-integer non-linear programming (MINLP) model and sensitivity analysis	Maximization of total expected revenue (TER) and creation of sustainable and circular virtual supply chains using blockchain and IoT technologies
[45]	Customer data analytics for immersive virtual experiences in interconnected virtual worlds	Quantitative literature review of databases and elimination criteria for article selection	Importance of customer data analytics in shaping immersive digital and metaverse brand experiences in virtual marketplaces

V. Conclusions

By integrating blockchain technology into the metaverse, users can establish secure ownership of their digital assets using non-fungible tokens (NFTs), opening the door to vibrant virtual economies. Moreover, blockchain enhances trust and security in the metaverse by eliminating the need for a central authority and ensuring transparency through recorded transactions on the blockchain. Additionally, blockchain enables interoperability among different metaverse platforms, expanding opportunities for cross-platform interactions and experiences. However, it's essential to acknowledge that incorporating blockchain into the metaverse comes with challenges related to scalability, energy consumption, and user experience. Despite these hurdles, the integration of blockchain has the potential to enhance digital interactions and self-expression. While blockchain technology offers numerous advantages, it also has its limitations and obstacles that need to be addressed. As technology advances and we find solutions to these challenges, blockchain could become an integral part of the metaverse, contributing to a future where human connection knows no boundaries and where collaboration and innovation flourish. The metaverse represents an extraordinary opportunity for human progress, where the boundaries between reality and the digital world seamlessly merge to enrich our lives and shape the course of human evolution.

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