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The Meta-Fusion:
A Cloud-Integrated Study on Blockchain Technology Enabling Secure and Efficient Virtual Worlds

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ABSTRACT

Blockchain technology and the metaverse are revolutionizing digital experiences by merging secure, cryptographic systems with shared virtual spaces. These advancements have immense potential across various sectors, including social interaction, education, and commerce. Despite these enhancements, current research remains fragmented. Thus, a comprehensive exploration of this domain is needed. This article conducts a systematic mapping study to understand research trends, challenges, and opportunities in the blockchain-based metaverse. The authors scrutinized 43 articles, categorizing them based on research themes and methodologies. Their analysis revealed a significant focus on technical aspects like blockchain implementation in virtual worlds and the design of virtual economies. The authors also found research that explores the social and cultural impacts of the blockchain-based metaverse. This study, thus, underscores the potential of the evolving field, emphasizing the need for research to fully understand its technical and societal implications. It also stresses the importance of evaluating the long-term sustainability, scalability, and potential risks associated with this promising, complex domain.

KEYWORDS

Blockchain Technology, Gaming, Metaverse, Social Networking, Sustainability, Virtual Reality, Virtual Space

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INTRODUCTION

The metaverse is a virtual shared space created by the convergence of virtually enhanced physical reality and physically persistent virtual space. This includes the sum of all virtual worlds, augmented reality, and the internet (Chen & Chen, 2020). The metaverse concept has been popularized in science fiction. In recent years, it has garnered significant attention as a potential platform for applications that promote social interaction, education, entertainment, and commerce.

Blockchain technology, a decentralized and distributed ledger, allows for secure and transparent record-keeping and transfer of assets (Nakamoto, 2009). It has also been suggested as a potential foundation for building metaverse platforms. The use of blockchain in the metaverse could enable the creation of virtual economies in which users buy, sell, and trade virtual goods and services. This could, in turn, allow for the creation of virtual real estate and virtual currencies.

There has been a growing body of research on the potential use of blockchain in the metaverse. Studies have focused on the technical challenges and opportunities of implementing blockchain in virtual worlds, the design of virtual economies and governance structures, and the potential impact of blockchain-based metaverse on society and the economy (Chen & Li, 2018). Research has also focused on the technical aspects of building a blockchain-based metaverse (e.g., scalability, security, and interoperability). Other studies have examined the economic implications of the blockchain-based metaverse, including the potential for creating new forms of value or the role of virtual currencies and assets (Kim & Lee, 2019). Significant research has highlighted the blockchain-based metaverse's potential social and cultural impacts, while other studies have explored the potential for the metaverse to facilitate new forms of social interaction and community formation. In contrast, others have examined the ethical and legal implications of virtual economies and virtual property (Liu & Li, 2017).

However, much of this research is still in its early stages. Several open questions and challenges should be addressed to fully understand blockchain's potential in the metaverse. For example, there is a need for more research on the long-term sustainability and scalability of blockchain-based metaverse platforms, as well as the potential risks and unintended consequences of virtual economies and virtual property.

Overall, the current state of research on blockchain-based metaverse is in its early stages. Thus, there is a need for further research to explore the technical, economic, and social implications of this technology. A systematic mapping study on this topic could provide a valuable overview of the existing research on blockchain-based metaverse, identify trends and gaps in the literature, and guide future research in this area.

This article is organized as follows. Section 2 provides an overview of blockchain technology, its core concepts, and the justification for implementing blockchain in the metaverse. Section 3 covers the systematic mapping study's approach, questions, databases, and study selection. In Section 4, the authors show the results of the data analysis. This includes a bibliometric overview, analysis of the data and its characteristics, and an assessment of the quality of the relevant literature. The results and their interpretation are discussed in Section 5, alongside the analysis and resolution of the study questions posed in the introduction. The article is summarized in Section 6, where findings are derived and suggestions for further research are offered.

PRELIMINARIES

This section sets the groundwork for blockchain technology and its core concepts. Blockchain technology can be considered a decentralized database shared across a group of computers (Ezhilchelvan et al., 2018; Nakamoto, 2009). Introduced alongside Bitcoin, it addresses the long-standing issue of double spending. In Bitcoin, this is accomplished by reaching an agreement among a sizable fraction of "mining nodes" and adding their approval of valid transactions to the blockchain. Bitcoin and other cryptocurrencies were, in fact, the pioneering use case for blockchain technology.

However, introducing a cryptocurrency is not required to utilize blockchain technology for developing decentralized applications (Buterin, 2014).

Overview of Blockchain

Blockchain, a decentralized and distributed ledger technology, enables the development of a secure and transparent record of transactions. This technology forms the basis of cryptocurrencies like Bitcoin and produces a permanent, immutable record of data. In 2008, the unknown person or group named Satoshi Nakamoto (2009) published the white paper "Bitcoin: A Peer-to-Peer Electronic Cash System," which presented the blockchain concept for the first time. Satoshi Nakamoto proposed a new system for handling digital currency, one that did not rely on any one person or organization. Instead, it focused on a decentralized network of computers.

A blockchain may be broken down into its most fundamental component: a network of computers that collaborate to verify and record transactions. These exchanges may involve anything of value like monetary funds, tangible items, or intangible services. Every transaction is written on a "block," which is then appended to the end of a "chain" that contains the transactions that came before it (Tapscott & Tapscott, 2016).

The fact that a blockchain is decentralized and dispersed across multiple locations is its defining characteristic (Aldweesh & VanMoorsel, 2016). First, this indicates there is no centralized authority that controls the network. Second, it shows that the ledger is distributed evenly throughout all the machines within the network. Thus, it is challenging for any one individual or group to manipulate the data stored on the blockchain (Aldweesh et al., 2021).

A blockchain relies on a consensus mechanism to verify and record transactions. Before a transaction is added to the blockchain, the computers that are part of the network will go through this procedure to determine whether it is legitimate. The "proof of work" mechanism is one of the most often used consensus procedures, pitting computers across a network against one another to solve a difficult mathematical issue (Gervais et al., 2016). The transaction is validated and added to the blockchain once it is completed on the first machine that solves the puzzle. This process is termed "mining."

The open and transparent nature of the blockchain technology is another essential facet of this emerging technology. Once a transaction has been added to the blockchain, it cannot be changed or removed. It is, therefore, accessible to everyone on the network. Furthermore, once a transaction has been published to the blockchain, it cannot be altered or deleted (Gervais et al., 2016). Due to this transparency, blockchain technology is especially beneficial for applications in which trust and transparency play a crucial role. Examples include the management of supply chains, voting systems, and financial transactions (Zhang & Li, 2018).

There are many kinds of blockchain. The most common are public and private blockchains. Public blockchains, like the one used for Bitcoin, may be accessed by any individual. They are protected by a decentralized network of computers. Private blockchains, on the other hand, are accessible to a limited number of users. These are typically employed for commercial or organizational purposes (Ezhilchelvan et al., 2018).

Blockchain technology has the potential to transform a variety of industries, including the financial sector, the healthcare industry, and supply chain management. It is already being utilized in a range of applications and it is anticipated that its utilization will continue to expand.

However, there are obstacles that must be addressed before blockchain technology can become widely used. For instance, scalability is a significant challenge because the number of transactions that can be handled on a blockchain is constrained by the capabilities of the network. Legislation is another barrier as governments and regulatory organizations determine how to approach the use of blockchain technology and cryptocurrencies.

In general, the technology behind blockchain has the potential to bring about substantial shifts in business and trade. This technology is still in its early phases. Thus, its full potential has not yet been realized.

Smart Contract and DApps

A smart contract is a self-executing contract with the terms of the agreement between buyer and seller written into lines of code. The code and agreements exist on the blockchain network (Buterin, 2014). Smart contracts allow for the automation of contract execution and enforcement, reducing the need for intermediaries and increasing the speed and efficiency of executing agreements. They also provide a higher level of security and accuracy. The terms of the contract are automatically enforced by the network, reducing the possibility of errors or fraud.

Smart contracts have the potential to revolutionize industries by streamlining and automating contract-related processes. They are most associated with blockchain technology and are often used in conjunction with decentralized applications or DApps (Gervais et al., 2016).

Blockchain platforms include:

- **Bitcoin:** This decentralized cryptocurrency uses peer-to-peer technology to facilitate transactions. It was the first and remains the most well-known blockchain platform (Nakamoto, 2009).
- **Ethereum:** This decentralized platform runs smart contracts or applications as programmed without any possibility of downtime, censorship, fraud, or third-party interference (Buterin, 2014).
- **Hyperledger Fabric:** This is an open source blockchain platform designed for use in enterprise contexts. It allows users to build and deploy applications and smart contracts on a modular and configurable platform (Androulaki et al., 2018).
- **Corda:** This blockchain platform was designed for use in the financial industry, allowing institutions to build and deploy applications that use smart contracts to facilitate transactions and record-keeping (Brown et al., 2016).
- **EOS:** This is a decentralized operating system designed to support industrial-scale decentralized applications. It uses a unique consensus algorithm, delegated proof of stake (DPoS), to achieve fast transaction times and high scalability (Xu et al., 2019).

Distributed Consensus Protocols

The term "distributed consensus protocols" refers to a class of algorithms that enables multiple nodes or devices that are part of a distributed system, such as a blockchain, to come to an agreement on a single data value or a single state of the system. This type of agreement can be beneficial in several situations. These protocols make it possible for nodes inside a decentralized system to reach a consensus on the system's state without the involvement of a centralized authority (Xiao et al., 2020).

There are numerous variants of distributed consensus protocols. Each has a distinct set of attributes and a separate set of advantages and disadvantages. The proof-of-work (PoW) protocol, the proof-of-stake (PoS) protocol, and the DPoS protocol are common examples of distributed consensus protocols.

PoW protocols, such as the one utilized by Bitcoin, require nodes to execute a particular amount of computational effort to submit a new block to the chain. This confirms the validity of the proposed block. This labor, also known as mining, contributes to the network's overall security by making it more difficult and costly for an adversary to seize control of the network (Yagmur et al., 2021).

PoS protocols, on the other hand, do not demand computing labor from the nodes in the network. Instead, for a node to propose a new block, it must be able to demonstrate that it is in possession of a particular number of tokens (Vasin, 2014).

Other forms of distributed consensus protocols, including Paxos and Raft, are utilized in distributed systems that do not depend on a blockchain. These protocols are also used to reach a consensus over transactions in distributed systems (Xiao et al., 2020).

Distributed consensus protocols, in general, are an essential component of decentralized systems because they enable nodes to reach a consensus on the state of the system without the intervention of a centralized authority. Thus, they are immune to censorship and can function in a manner that is completely distrustful.

Blockchain in the Metaverse

The merging of virtually improved physical reality and physically persistent virtual space includes the sum of all virtual worlds, augmented reality, and the internet. This, in turn, creates the metaverse. The metaverse is a virtual shared area that can be used by multiple people at the same time (Zhao et al., 2020).

There are several scenarios in which a blockchain could prove valuable within the metaverse. They include:

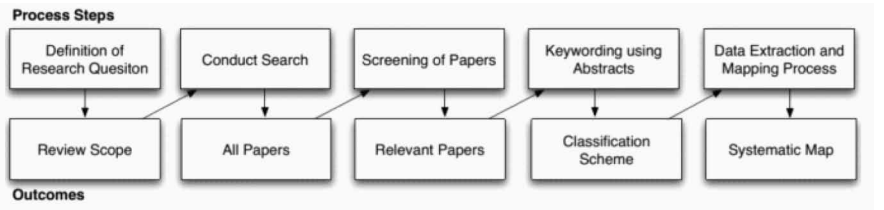
- **Decentralization:** A blockchain can provide a decentralized platform for the metaverse, which enables a better degree of security and resistance to attacks and censorship.
- **Immutable Record-Keeping:** A blockchain has the potential to offer an immutable record of all transactions and events that take place within the metaverse. This would guarantee that the history of the metaverse could not be changed.
- **Digital Ownership:** A blockchain can provide a secure, transparent mechanism to monitor the ownership of digital assets within the metaverse. These include virtual real estate, virtual cash, and virtual commodities. This can be accomplished with the use of a distributed ledger.
- **Smart Contracts:** The use of smart contracts can be enabled by a blockchain, which can automate the management and execution of complicated transactions within the metaverse.

Overall, a blockchain can provide a reliable foundation for the operation and governance of the metaverse. First, this can help to build trust. Second, it can enable the metaverse to function as a decentralized platform for a range of applications and use cases. Blockchains are also referred to as distributed ledger technology or DLT (Chen & Li, 2017; Kim & Lee, 2018; Liu & Li, 2016).

METHODOLOGY

The authors used the systematic mapping study in Petersen et al. (2008) as the basis for their research approach, which studied previous research on smart contracts. Using the findings of the comprehensive mapping study, the authors could identify and map research areas associated with smart contracts. In addition, the authors were able to identify research gaps that should be considered in subsequent studies. As shown in Figure 1, the methodology for the systematic mapping study can be broken into five parts.

Figure 1. Systematic mapping study process (Petersen et al., 2008)



Defining the Research Questions

Based on the authors' goal of understanding the current state of knowledge regarding blockchain's potential metaverse applications, they formulated the following four research questions in the first phase of their systematic mapping study.

1. **How have studies addressed blockchain-based techniques and the metaverse?** The goal of this study is to better understand the various metaverse settings in which blockchain technology has been proven to be useful. The authors can determine which metaverse issues can be addressed by blockchain. They can also identify which metaverse issues can be explored via other methods (like scouring scholarly works). Given the media frenzy in which many problems are deemed addressable by blockchain, a map of Metaverse problem domains in which blockchains are relevant will help researchers and practitioners focus their attention on those potential areas of blockchain application in the sector.
2. **How effective is the use of blockchain in the metaverse?** It has been argued that blockchain technology might be used in a variety of contexts. However, not all the ideas have been developed into fully functional prototypes. This highlights effectiveness and the significance of learning about the breadth of existing blockchain-based metaverse application implementations in connection to the identified use cases. This will aid in drawing attention to the need to shift the research focus toward understudied regions.
3. **What are the drawbacks and limitations of blockchain-based applications in the metaverse?** This aims to explore the obstacles within the metaverse blockchain applications.
4. **What are the unanswered questions and potential research directions?** The final question considers open questions for future studies. By identifying research gaps and field obstacles, researchers can better direct their future efforts.

Research

In step two of the systematic mapping study, the authors identified primary papers by searching scientific databases with a certain string of text or keywords. The authors looked for relevant articles in IEEE Xplore, ACM Digital Library, ScienceDirect, Web of Science, and Scopus. The authors aimed to narrow their research to include items that have been approved for publication in high-quality academic venues like journals, conferences, seminars, and books.

Blockchain AND Metaverse was the search string used to scour the databases. No results were found when these metaverse-related phrases or their derivatives or acronyms were joined with "blockchain," indicating that the search string adequately captured all the concepts. Alternatives to "blockchain" (like "distributed ledger technology") did not produce additional results. This is a novel area of research; therefore, the authors searched for relevant literature without imposing time constraints on the process. The results are presented here.

Screening Research Papers

The papers were retrieved from databases using the authors' search strategy. Then, the papers were screened for relevancy. Article titles were examined to determine if they were relevant to the procedure. The authors disregarded papers that were irrelevant to the research. In addition, the authors had to remove papers that had nothing to do with using blockchain technology in the medical field.

A paper was sent to the next round of screening if relevance could not be determined by its title. Phase two of the screening process involved reading abstracts of accepted articles. The authors sometimes had to read the introduction and conclusion to assess whether the article met their exclusion criteria.

Non-peer-reviewed papers (such as interviews and press releases), papers without full text availability, papers whose primary focus is not on the use of blockchain technology in the metaverse, duplicate papers, papers written in languages other than English, and retracted papers were disqualified

from consideration. Those papers that did not meet these exclusion criteria but were still thought to be primarily about applying blockchain technology in the metaverse were moved to the next round of the mapping project.

Keywords Based on the Abstract

This process aimed to classify the relevant research publications in the literature. This was accomplished by following the steps outlined in Zhao et al. (2020), as shown in Figure 4. Keywords and topics that reflect the paper's contributions were extracted from the abstracts of the publications. The papers were organized into groups by topic via these keywords. After the papers were grouped into their respective categories, they were read individually. Any changes were made based on the contents. When it became clear that no preexisting category adequately described the article, a new one was introduced. The final product of this procedure is a classification scheme for all the relevant publications.

Extracting and Mapping Data

The extraction and mapping of data is a vital step in conducting research. It allows the authors to collate and analyze information that will answer the study's research questions. This study employed specific techniques to extract data from selected papers. The data encapsulates the main objectives and contributions of each study.

This study was driven by the need to understand current trends, challenges, and opportunities in the burgeoning field of blockchain-based metaverse. Despite increasing interest in this domain, research remains fragmented. A systematic approach to collate and analyze existing studies is needed. Therefore, the authors aim to provide a comprehensive overview of the current research landscape in blockchain-based metaverse, bridging gaps between fragmented studies and offering a holistic understanding of the field.

Through meticulous extraction and mapping of data, the authors categorized the studies based on research themes and methodologies. Their work offers valuable insights into focus areas within the field. This process further illuminated the technical aspects that researchers are exploring, such as the implementation of blockchain in virtual worlds, the design of virtual economies, and the social and cultural impacts of blockchain-based metaverse.

In essence, the techniques used for data extraction and mapping significantly contribute to the understanding of blockchain-based metaverse. By providing a comprehensive overview of the field, the authors hope to spur research into this complex domain, ultimately contributing to its sustained growth and development.

RESULTS

This section discusses the results of the systematic mapping study carried out on blockchain-based metaverse. First, the authors review the findings of the search and preliminary screening for relevant papers. Next, the authors discuss the classification outcomes.

Searching and Screening for Relevant Papers

Section 3 described the first two stages of a systematic mapping study (searching and screening for relevant materials). This subsection discusses the steps and outcomes that resulted from the mapping. During the research process, the authors combed through numerous academic databases for articles that use "blockchain" and "metaverse." There were 335 papers collected across the databases as of January 2023.

First, during the screening process, the authors used the titles and abstracts to remove documents that were not relevant. In total, the authors excluded 291 papers. First, many documents did not pertain to the current research because the authors were investigating blockchain-based metaverse from a

technological standpoint. For instance, several articles discussed the topic from an economic or legal perspective. Second, some publications were excluded because they addressed topics unrelated to the current research concerns, such as the metaverse's financial or social impact.

To achieve the final count of 46 papers, the authors had to remove 117 duplicates. Of the original 335 papers, 175 were dropped because they only offered a background or review information. Therefore, the authors limited their work to 43 papers, maintaining a systematic mapping study. Table 1 and Figure 2 provide an overview of the outcomes and screening of the search.

Classification Outcomes

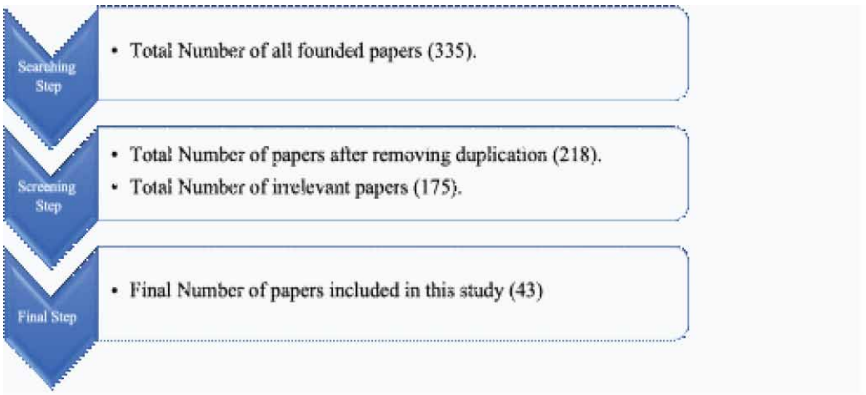
The authors were unable to locate existing blockchain-based metaverse mapping research. Therefore, they developed unique classifications by applying key-wording techniques. Using these criteria, the authors established the following classification:

1. Select a representative sample of the papers.
2. Read the title, abstract, and conclusions (and keywords, if provided).
3. If the document can be classified under an existing heading, do so. Otherwise, make a new classification.
4. Once sample papers are completed, proceed to next four with the remaining papers. If there is too much duplication, remove categories and return to step 2.

Table 1. Database search results

Database	Total of Founded Research Papers
IEEE Xplore	60
ACM	61
ScienceDirect	21
Web of Science	60
Scopus	133

Figure 2. Searching and screening process



Hence, the metaverse can be divided into several categories based on its process:

- **Gaming:** Users can engage in multiplayer games, compete in tournaments, or participate in role-playing activities.
- **Socializing:** Users can meet and interact within a virtual social setting.
- **Education and Training:** Students and professionals can learn or practice skills in a virtual setting.
- **Business and Commerce:** Users can access a virtual marketplace to buy or sell goods and services with virtual currencies or blockchain-based tokens.
- **Art and Culture:** The platform can be used for creative expression and cultural exchange, allowing users opportunities to experience and participate in virtual art installations, concerts, and other events.
- **Healthcare:** Users can access virtual therapy sessions or telemedicine consultations.
- **Security Issues and Enhancement:** Research contributes to improved security and improvements within the system.

Gaming

The emerging field of blockchain-based gaming in the metaverse has the potential to revolutionize how games are designed and played. For instance, non-fungible tokens (NFTs) are used to represent unique in-game items like rare weapons. These can then be bought and sold in the same manner as physical items. Vidal et al. [24] discussed the emergence of NFTs, the growing trend of play-to-earn gaming, and metaverse tokens. NFTs are unique digital assets that are authenticated on a blockchain and cannot be exchanged for other assets. Play-to-earn games allow players to earn cryptocurrency through their game play and metaverse tokens represent ownership of virtual real estate in virtual worlds. These new developments in the cryptocurrency market have the potential to disrupt traditional models of gaming and virtual reality.

Blockchain can be used to secure in-game transactions, ensuring that players are not cheated or scammed when buying or selling items. Yao et al. (2022) explored the concept of freedom and restraint within the metaverse, specifically through the lens of the blockchain game Dark Forest. The authors discuss how the game, which allows players to explore and create within its virtual world, has certain rules and limitations imposed by the game's developers and the underlying blockchain technology. The authors argue that while these restraints may seem to limit player freedom, they also provide a sense of security and stability within the game. The paper concludes by suggesting that the balance between freedom and restraint within the metaverse is a complex and ongoing issue that will continue to be addressed and negotiated by both players and developers.

Jiang et al. (2022) presented a hierarchical game-theoretic approach for reliable distributed computing in the metaverse. The approach involves organizing the metaverse into a hierarchical structure with different levels of trust and reliability, allowing for more efficient and effective distributed computing. They discuss the challenges and benefits of this approach, as well as its potential applications in fields like education and business.

Blockchain can also be used to create cross-game compatibility, allowing players to bring their in-game items and assets with them when they switch games. Wu et al. (2022) discussed the use of novel blockchain technologies to facilitate serverless match-based online games. The authors propose using these technologies to improve the efficiency and fairness of games by eliminating the need for centralized servers and enabling decentralized, peer-to-peer matchmaking. They also discuss the potential benefits of using blockchain for in-game microtransactions and player reputation management. The paper concludes by discussing the challenges and limitations of implementing these technologies in online gaming and outlining directions for future research.

Table 2. Gaming studies summary

Study	Description
Vidal- Tomás (2022)	Discussed the emergence of NFTs and play-to-earn gaming in the metaverse.
Yao et al. (2022)	Explored the concept of freedom and restraint in a blockchain-based game titled "Dark Forest."
Jiang et al. (2022)	Presented a hierarchical game-theoretic approach for distributed computing in the metaverse.
Wu et al. (2022)	Discussed the use of blockchain technologies in serverless, match-based online games.

Socializing: Verifying Identifications

From the literature, the authors found that blockchain is explored to support socializing in the metaverse. In addition, it has the potential to transform the way people interact within a virtual space.

Blockchain can be used to verify the identity of users in the metaverse, helping to prevent impersonation and fraud. Casale-Brunet et al. (2022) argued that using NFTs as profile pictures can add a level of personalization and uniqueness because they are unique digital assets that can be bought and sold. Their research also discusses the potential for NFT profile pictures to be used as a form of social currency within online communities, serving as a sign of status. Additionally, the authors explore the potential for NFTs to support and promote artists and creators within these communities. Overall, they suggest that NFT profile pictures have the potential to bring a new level of engagement and value to social network communities.

Ryu et al. (2022) discussed the design of a secure mutual authentication scheme for use in metaverse environments via blockchain technology. The scheme aims to provide a secure way for users to authenticate their identity while accessing virtual spaces within the metaverse. Blockchain allows for the creation of a decentralized system in which users' identities are verified and recorded, providing a secure foundation for the authentication process. The proposed scheme includes the use of biometric data and cryptographic techniques to ensure the authenticity and integrity of the authentication process. The goal of the scheme is to provide a reliable means of authenticating users within the metaverse, enabling secure access and trustworthy interaction within virtual spaces.

Lee and Gu (2022) proposed a scheme for authenticating digital citizens and promoting secure interactions or transactions within the virtual world. The details of the authentication process, as well as potential challenges and solutions, are discussed in their study.

Tao et al. (2022) presented the use of machine learning techniques to understand the structure of a blockchain transaction network in the context of the metaverse. Their work aims to learn the identity representation of nodes in the network to explore relationships between parties in the metaverse. The authors propose a method for structural identity representation learning that utilizes graph convolutional networks to analyze the network structure. They test the effectiveness of their method through experiments on real-world blockchain data, demonstrating that it outperforms existing methods in terms of accuracy and efficiency.

Socializing: Reputation Management

Blockchain can be used to track and manage reputation in the metaverse, allowing users to build an image based on their actions and interactions within the virtual world. Xu et al. (2022) discussed the potential for using blockchain technology to create a trustless architecture for the metaverse. The authors propose using a decentralized approach to manage and operate the metaverse, with nodes on the blockchain network used to verify and validate transactions within the virtual world. This

approach would ensure greater security and autonomy by eliminating the need for a central authority or intermediaries. The study also discusses potential challenges and limitations of implementing such an architecture, as well as potential applications and use cases for a blockchain-enabled metaverse.

Socializing: Secure Communication

Blockchain can be used to secure communication within the metaverse, ensuring that messages and other forms of communication are not intercepted or manipulated. Kang et al. (2022) discussed the use of blockchain in creating an incentive scheme for federated learning in an industrial metaverse. The goal is to optimize the age of information (AoI) in these environments. The proposed scheme utilizes a combination of blockchain and machine learning techniques to encourage participation in the federated learning process, ultimately leading to more accurate and up-to-date information shared among participants.

Ersoy and Gürfidan (2022) proposed Metarepo, a mechanism for storing and servicing assets on a blockchain within the metaverse. This system allows for the creation and transfer of digital assets, such as virtual goods and currencies, within the metaverse. The use of blockchain technology ensures the security and transparency of these transactions. The Metarepo also allows for the creation of smart contracts, which can be used to automate certain processes within the metaverse. Overall, Metarepo aims to provide a reliable and efficient method for users to interact with and utilize assets within the metaverse.

Socializing: Decentralized Social Networks

There are efforts to build decentralized social networks using blockchain technology. This would allow users to own and control their data rather than rely on centralized platforms for data management. According to Nakavachara and Saengchote (2022), this would impact the unit of account (UOA) on the willingness to pay (WTP) in the metaverse, specifically related to LAND transactions. The study found that UOA significantly affects WTP, with individuals willing to pay more when the UOA is in a more widely accepted and stable currency (like US dollars) rather than a less stable cryptocurrency. The results suggest that the choice of UOA can have a significant impact on market outcomes. Thus, it should be carefully considered in virtual environments.

Duan et al. (2022) discussed a method for creating unique user-generated content in the metaverse via cryptocurrency. The authors propose Crypto-Dropout, a system that utilizes blockchain technology to allow users to generate and share unique content linked to specific cryptocurrency data. The goal of this system is to create unique user-generated content while also encouraging users to engage with cryptocurrency information in the metaverse.

Huang et al. (2022) discussed the use of a pre-trained model method to generate a judgeview for online dispute resolution. This approach provides a more objective and unbiased perspective on disputes that are being resolved online. The study explains how the pre-trained model can be used to analyze the information or arguments presented in a dispute and provide a recommendation for resolution. The authors argue that this method can be more effective than relying on human judges, who may have biases and subjective interpretations of the dispute. Overall, the authors suggest that the use of a pre-trained model can improve the efficiency and fairness of online dispute resolution.

Talmon and Shapiro (2022) discussed the creation of a democratic metaverse. Their paper outlines the foundations for building this virtual world, including the need for strong governance structures and policies to ensure fairness and accountability and the importance of community participation in decision-making processes. They also explore the potential for using blockchain technology to create a decentralized, transparent, and secure system for governing the metaverse. Overall, the goal of their paper is to lay the foundations for a grassroots democratic metaverse that is open, inclusive, and participatory.

Xu et al. (n.d.) discussed the potential for using blockchain technology and spectrum management in the creation of a native communication system within the metaverse. The authors propose using a

decentralized network of nodes to facilitate communication, suggesting that spectrum management techniques could be used to optimize the allocation of resources within this network. The goal of this system is to create a seamless and efficient communication experience within the metaverse.

Ryskeldiev et al. (2018) discussed the creation of a decentralized blockchain-based model for peer-to-peer sharing of virtual spaces for mixed reality applications (a distributed metaverse). This model would allow for the creation and sharing of virtual spaces that can be accessed and experienced by multiple users in a decentralized manner. The use of blockchain technology would ensure that the virtual spaces are secure and transparent. In addition, it would enable users to easily access and share spaces with others. The authors suggest that the distributed metaverse could have numerous applications, including virtual reality gaming, social networking, and educational and business environments.

Socializing: Virtual Reality

Some researchers are exploring the use of blockchain technology to support VR experiences in the metaverse, including the creation of NFTs that represent unique VR experiences or environments. Deveci et al. (2022) discussed the development of a decision support system for evaluating and prioritizing sustainable urban transportation options in virtual reality environments. The system utilizes data on transportation modes, infrastructure, and user preferences to provide recommendations on the most sustainable transportation options for a given situation. The authors argue that this system has the potential to support more sustainable transportation planning in virtual environments and could be used to inform decision-making processes in the physical world.

Duan et al. (2021) discussed the creation of a prototype for a metaverse on a university campus that is intended to be used for social good. The metaverse would facilitate communication and networking, allowing students and faculty to engage in collaborative projects and events. The prototype includes features like virtual meeting spaces, virtual events, and virtual exhibitions. The platform is intended to be used for social activism, research, and community engagement. The authors discuss the potential benefits of this prototype, including increased accessibility, reduced environmental impact, and the ability to connect with people from diverse backgrounds. They also address challenges and solutions related to privacy and security.

Zhao et al. (2022) discussed the use of DAOs in the TransVerse system (a platform for smart mobility). Their work explains how DAOs within TransVerse can use federated intelligence to make decisions and improve the efficiency and effectiveness of the platform. The authors also discuss the potential benefits and challenges of using DAOs in the context of smart mobility, including issues related to governance and scalability. Overall, the authors suggests that the use of DAOs in TransVerse can create a more efficient, effective systems for smart mobility.

Kim et al. (2022) proposed MetaTwin, a system that aims to synchronize physical and virtual spaces to create a seamless world. The system uses a combination of sensors, cameras, and virtual reality technology to track the movements and actions of individuals in both physical and virtual spaces, allowing them to interact in real-time. The goal of MetaTwin is to create a more immersive and interactive experience for users, creating virtual environments that are more closely tied to the real world.

Education and Learning

The authors found several ways that blockchain technology is used to support education and learning in the metaverse. Researchers are exploring the use of blockchain technology to support VR education in the metaverse, including the creation of NFTs that represent unique VR educational experiences or environments. Hwang (2023) discussed the effects of creating a metaverse exhibition featuring (NFTs) in maker education. They found that participating in the exhibition increased makers' understanding of NFTs and the metaverse, as well as their confidence in their ability to create and sell their own NFTs. It also led to increased collaboration and a sense of community among the makers. The authors

Table 3. Socializing summary

Study	Description
Casale-Brunet et al. (2022)	Investigated the potential of using NFTs as profile pictures within social networks.
Ryu et al. (2022)	Explored the design of a secure mutual authentication scheme for metaverse environments using blockchain.
Lee and Gu (2022)	Proposed a scheme for authenticating digital citizens in a virtual world (the metaverse).
Tao et al. (2022)	Presented the use of machine learning techniques to analyze blockchain transaction networks in the metaverse.

suggest that incorporating NFTs and the metaverse into maker education can be a valuable way to engage students and foster skills in digital literacy and entrepreneurship.

Business and Commerce

Business and commerce in the metaverse refer to the buying and selling of goods and services within virtual environments or online marketplaces. Blockchain can be used to facilitate business and commerce in the metaverse. For example, it can be used to create secure and transparent payment systems, verify the ownership and authenticity of virtual assets, and create smart contracts that automate the execution of commercial agreements.

Lin et al. (2022) proposed a blockchain-based system for trusted collaborative governance in the metaverse. The system would allow for the creation and management of digital assets, as well as the tracking of ownership and transfer of these assets. It would also enable the creation of smart contracts and the ability to enforce rules and regulations within the metaverse. The authors argue that this system would improve the trust and transparency of interactions within the metaverse, as well as facilitate the growth and development of the metaverse.

Maksymyuk et al. (2022) considered the use of blockchain technology to manage services in the decentralized metaverse of things (DMoT), a virtual network of interconnected devices and objects that interact with each other and users. Their work proposes using blockchain to enable the creation, management, and execution of services within the DMoT. They also discuss the benefits of using blockchain, including its ability to ensure the integrity and security of services and its potential to enable new business models and revenue streams.

Cao (2022) described the creation and use of a theory based on metal random matrices in a numerical phantom of the metaverse NFT. The purpose of this theory is to provide a more accurate representation of the metaverse and its interactions with NFTs. The theory is tested and applied in a numerical phantom, a simulated environment used to study and understand complex systems. The results of the study suggest that the metal random matrix-based theory can improve the accuracy of NFT simulations in the metaverse.

By using blockchain to record transactions and facilitate interactions within the metaverse, it is possible to create a decentralized and transparent economic system that operates independently of any central authority. This can create a more open, accessible marketplace that enables new forms of economic activity unattainable in the physical world. Wang et al. (2022) discussed the potential for NFTs in the metaverse, arguing that they can be used to facilitate multimodal interactions that enhance the utility and value of tokens. The article also discusses the importance of decentralization in the metaverse, noting how NFTs help to maintain a decentralized system (rather than a centralized one controlled by a few powerful entities). Overall, the authors argue that NFTs have the potential to bring value to the metaverse by enabling more interactive and engaging experiences for users.

Lian (2022) proposed a blockchain-based system for managing large amounts of data related to international trade. The system aims to provide secure and trusted distribution of data by using the decentralized and immutable nature of blockchain technology. The system can be used to track and verify trade transactions, prevent fraud, and streamline the process of international trade.

Dai (2022) discussed the use of federated learning for optimizing the policy computation of blockchain-based smart contracts. Federated learning is a machine learning technique that allows for decentralized training of a model by allowing multiple parties to train on their own data without sharing it with each other. The authors propose using federated learning to optimize the policy computation of smart contracts. The use of federated learning in this context allows for the optimization of these policies without requiring the sharing of sensitive data.

Arts and Culture

Blockchain technology has the potential to transform the art and cultural sectors within the metaverse. For instance, digital art and other virtual cultural assets may be bought, sold, and traded on the blockchain. This can then provide a new channel for artists and creators to monetize their work and reach a global audience.

Shahriar and Hayawi (2022) described a method for generating (or NFT) art using generative adversarial networks (GANs). The authors propose using GANs to create original NFT art. Then, they would compare the results to human-generated art to assess the quality of the generated work. The results show that the GAN-generated art can produce high-quality art that is indistinguishable from human-generated art. This method would allow for the creation of unique digital art that can be bought and sold on the blockchain with ease.

Varinlioglu et al. (2022) studied how augmented reality can enhance the viewing and creation of digital art. Their work also considers challenges and opportunities for artists and galleries in the age of the metaverse.

Moreover, blockchain can be used to verify the ownership and authenticity of digital art and cultural assets. This can reduce the risk of counterfeiting and fraud, creating a more trustworthy market for these assets. Wei (2022) proposed Gemiverse, a platform that uses blockchain technology to provide professional certifications and tourism services within the metaverse. With its own ecosystem within the metaverse, Gemiverse allows users to interact and engage with each other and the platform. Gemiverse aims to provide a new way for professionals to showcase their skills and for tourists to discover and experience new destinations.

In addition, blockchain-based tools can be used to automate the licensing and distribution of digital art and cultural assets, helping artists and creators monetize their work. In addition, consumers will be able to access a range of cultural content. Guidi and Michienzi (2022) discussed the emergence of a new type of fraud involving (NFTs) termed "sleepminting." Sleepminting involves creating fake

Table 4. Business and commerce summary

Study	Description
Lin et al. (2022)	Proposed a blockchain-based system for trusted collaborative governance in the metaverse.
Maksymyuk et al. (2022)	Considered the use of blockchain technology to manage services in the decentralized metaverse of things (DMoT).
Cao (2022)	Described the creation and use of a new theory based on metal random matrices in a numerical phantom of the metaverse NFT.
Wang et al. (2022)	Discussed the potential for NFTs in the metaverse.

Table 5. Art and cultural summary

Study	Description
Shahriar and Hayawi (2022)	Described a method for generating NFT art using generative adversarial networks (GANs).
Varinlioglu et al. (2022)	Explored the use of augmented reality in digital art and its potential impact on the art world.
Wei (2022)	Proposed the Gemiverse, a platform that uses blockchain technology to provide professional certifications and tourism services within the metaverse.

NFTs and selling them to unsuspecting buyers as genuine. Their work describes this type of fraud and its risks to investors. It also discusses solutions for preventing and combating sleepminting.

Healthcare

Blockchain technology has the potential to revolutionize healthcare within the metaverse by enabling the secure and transparent exchange of data and information. For example, a blockchain-based healthcare system in the metaverse could be used to store and manage electronic medical records, enabling patients to access their health information and share it with other providers as needed. This leads to improved accuracy and efficiency of care, as well as reductions in errors and miscommunication.

Wu et al. (2022) presented an architecture for an emergency rescue system based on the metaverse. In it, rescuers can remotely access virtual reality technologies to navigate an emergency scene. The proposed system also incorporates sensors and other devices to provide real-time data about conditions on the ground. In turn, rescue teams can assess the situation and make informed, accurate decisions. This proposed architecture has the potential to significantly improve emergency response times, enhance the safety, and improve the effectiveness of rescue efforts.

Bhattacharya et al. (2022) discussed the use of the metaverse in telesurgery (surgery performed remotely) in the context of healthcare 5.0, a futuristic vision of healthcare that combines artificial intelligence (AI), digital technologies, and personalized medicine. The authors suggest that the use of blockchain technology and explainable AI can help facilitate the integration of the metaverse into healthcare 5.0, which improves the efficiency and effectiveness of telesurgery. They argue that the combination of these technologies enables secure data sharing and transparency. It also provides an explanation of the AI decision-making process, which is vital in a medical context. Finally, the authors discuss potential challenges and ethical considerations related to the use of the metaverse in telesurgery, including privacy, security, and liability.

Song and Qin (2010) explored the use of the metaverse in personal healthcare, suggesting that the metaverse can provide virtual therapy sessions and patient access to remote healthcare services. Thus, the need for in-person visits is reduced. The authors also discuss the potential for the metaverse to be used as a platform for educating healthcare professionals or creating virtual support groups for individuals with chronic conditions. They concluded with a call for more research and development in this area.

Blockchain-based healthcare systems in the metaverse could also be used to facilitate the exchange of healthcare-related data and information between stakeholders (e.g., patients, providers, insurers, and researchers). This could enable new insights and knowledge, driving innovation and improvements in the healthcare sector.

Liu et al. (2022) proposed a conceptual framework for using blockchain technology to enhance the modeling of information in the field of healing and therapeutic design. Their study suggests that blockchain could be used to securely store and share data related to therapeutic interventions, allowing

for more accurate and effective treatment plans. The framework includes several key elements like the integration of blockchain into existing information systems, the creation of a shared database of therapeutic interventions, and the development of protocols for data access and privacy. Overall, the authors argue that this framework can revolutionize the way therapeutic interventions are designed and implemented, ultimately leading to improved patient outcomes.

Security

Blockchain technology can be used to enhance security in the metaverse. For instance, blockchain-based smart contracts can be used to automate the execution of security-related processes and protocols. Smart contracts may be used to manage access to virtual assets and environments, enforce security and privacy policies, and alert stakeholders to potential security threats. Cui (2022) discussed the use of consortium blockchain technology in cross-chain systems, specifically in the context of the metaverse and multi-chain environments. Their study also discussed the potential use of quantum cryptography within systems to enhance security. In summary, their work examined the intersection of blockchain technology, cross-chain systems, and quantum cryptography in the context of virtual reality and multi-chain environments.

Blockchain technology can also be used to create secure and transparent systems for storing and exchanging data and information within the metaverse. This can reduce the risk of data breaches or other security incidents and protects user privacy. The MetaChain framework, a blockchain-based system designed for use in metaverse applications, includes virtual environments that can be accessed online (Nguyen et al., 2022). The framework utilizes a distributed ledger technology to securely store private data and facilitate transactions within the metaverse. The authors of this article argue that the MetaChain framework can facilitate the growth and development of the metaverse, revolutionizing how we interact and engage with virtual worlds.

Badruddoja et al. (2022) discussed the use of blockchain technology to enhance the trustworthiness of AI within the metaverse, a virtual reality space that connects users. The authors suggest that incorporating blockchain into AI systems can provide a transparent and secure record of data processing, helping to ensure that AI decisions are fair and unbiased. Additionally, the use of blockchain can help to prevent tampering and fraud within the metaverse. Overall, they found that integrating blockchain into AI systems within the metaverse can lead to a more trustworthy, reliable virtual reality user experience.

Finally, blockchain technology can be used to create decentralized and distributed systems that are resistant to attacks and failures. This can ensure the availability and reliability of virtual assets and services, creating a more secure and stable metaverse. Gai et al. (2022) discussed the use of blockchain technology to create a multi-signature lock system for user account control (UAC) in the metaverse (virtual reality environments). The system would allow multiple parties to jointly control

Table 6. Healthcare summary

Study	Description
Wu et al. (2022)	Presented an architecture for an emergency rescue system based on the metaverse.
Bhattacharya et al. (2022)	Discussed the use of the metaverse in telesurgery in the context of healthcare 5.0.
Song and Qin (2022)	Debated the potential use of the metaverse in the realm of personal healthcare.
Liu et al. (2022)	Proposed a conceptual framework for using blockchain technology to enhance the modeling of information in the field of healing and therapeutic design.

access to a user account, providing added security and accountability. The authors propose the use of smart contracts to automate the process of granting and revoking access to the account. Additionally, they suggest that the integration of this system into existing identity verification protocols can further enhance security and prevent unauthorized access. Overall, the system provides a secure and efficient method for managing user accounts in the metaverse.

Aloqaily et al. (2022) argued that this integration allows for more realistic and immersive experiences in the metaverse, as well as the potential for practical applications like remote communication and training. They also discuss the challenges and considerations for implementing this integration, including data privacy and security.

Overall, the use of blockchain technology to enhance security in the metaverse can create a more secure and trustworthy virtual environment. It also enables the creation and dissemination of a range of virtual assets and services.

DISCUSSION

This part summarizes the findings of the study and provides responses to the concerns posed by the research that were outlined in Section 3.

Q1: Research, Blockchain-Based Techniques, and the Metaverse

Recent studies have spotlighted the use of blockchain technology in the metaverse. Examples include: virtual marketplaces for buying and selling goods or services within virtual environments; digital asset exchanges for trading virtual real estate, collectables, and other items; virtual reality training and education platforms that use blockchain technology to create and track educational content and verify the completion of training programs; and in-game economies in which users can earn and spend virtual currency.

It is evident that blockchain technology can be used to create a secure and transparent ledger for tracking virtual currency transactions. These techniques and applications demonstrate blockchain technology's potential to enable new forms of economic activity as it creates and distributes virtual assets and services within the metaverse.

Q2: Effect of Blockchain in the Metaverse

Blockchain technology has the potential to enable new forms of economic activity and facilitate the creation and distribution of a range of virtual assets and services within the metaverse. It can

Table 7. Security issues and enhancement summary

Study	Description
Cui (2022)	Discussed the use of consortium blockchain technology in cross-chain systems, specifically in the context of the metaverse and multi-chain environments.
Nguyen et al. (2022)	Described a blockchain-based system designed for use in metaverse applications.
Badruddoja et al. (2022)	Discussed the use of blockchain technology to enhance the trustworthiness of artificial intelligence (AI) within the metaverse.
Gai et al. (2022)	Discussed the use of blockchain technology to create a multi-signature lock system for user account control (UAC) in the metaverse.
Aloqaily et al. (2022)	Argued that the integration of blockchain technology will allow for more realistic and immersive experiences in the metaverse.

provide a secure, transparent platform for buying and selling goods and services. In addition, it can verify ownership and authenticity of digital assets and automate the execution of commercial agreements. The decentralized and distributed nature of blockchain technology can also help to ensure the availability and reliability of virtual assets and services. This creates a more secure and stable metaverse.

Overall, the use of blockchain technology in the metaverse has the potential to create a more efficient and transparent virtual environment, enabling new forms of economic and social interaction. However, as with any new technology, there may be challenges and limitations that need to be addressed to fully realize its potential.

Q3: Drawbacks and Limitations of Blockchain-Based Applications in the Metaverse

Blockchain technology has tremendous potential in the metaverse; however, there are many challenges to overcome. Limitations in supporting several use cases in the metaverse can be attributed to the current generation of blockchain technology's inability to scale to a high transaction volume. Problems with interoperability arise from the fact that there are several competing blockchain platforms. This makes it challenging to interoperate between systems or exchange data and assets.

A stable, predictable working environment can be achieved through the clarification of legal and regulatory concerns that arise from the implementation of blockchain technology in the metaverse. Blockchain's inherent complexity might be a turnoff, especially for casual users. To facilitate widespread adoption of blockchain-based applications in the metaverse, user-friendly interfaces and tools must, therefore, be developed. Lack of education on blockchain technology is also a barrier to widespread adoption and use.

In sum, resolving these issues and restrictions is essential if blockchain technology is to facilitate the production and distribution of a vast array of digital goods and services.

Q4: Questions and Research Directions

Areas for the study of blockchain's potential application in the metaverse include layer 2 solutions, sharding, and off-chain transactions. It is also important to investigate cross-chain protocols, atomic swaps, and interoperability layers as potential means by which several blockchains might communicate with each other.

- **Regulation:** Explore the metaverse's legal and governing bodies' thoughts on blockchain technology's applications and determine how to alleviate any worries.

For greater metaverse-wide adoption of blockchain-based apps, user experience designers should prioritize the creation of intuitive interfaces and tools. This can be achieved by:

- Promoting the use of blockchain systems in the metaverse by creating educational materials and activities for the public.
- Preserve the security of blockchain-based systems in the metaverse by investigating current threats and developing threat-related solutions.
- Investigating and mitigate potential risks to users' privacy posed by the deployment of blockchain technology in the virtual environment.

Consequently, these areas of research are crucial in the development of blockchain technology in the metaverse. Their adoption, in turn, will facilitate the production and distribution of an extensive catalogue of digital assets and services.

CONCLUSION

The article's systematic mapping study provides an overview of leading edge blockchain-based metaverse research. The authors identified a diverse set of contributions that covered technical, economic, social, health, art, and ethical aspects of this emerging field. A total of 43 studies explored the topic of blockchain-based metaverse. The results showed that most of the research in this field has focused on the use of blockchain technology to enable virtual worlds and gaming applications. Other common application domains included social networking, education, and e-commerce. The studies used a variety of blockchain technologies, particularly Ethereum and Hyperledger Fabric. The main challenges identified in the literature include scalability, security, and interoperability. The study also identified several promising research directions, including the use of blockchain technology to enable more immersive and interactive experiences in virtual worlds and the development of decentralized governance models for metaverse platforms.

The use of blockchain technology to build metaverse platforms has the potential to revolutionize the way we interact and do business in virtual environments. However, many challenges and opportunities must be addressed. First, more scalable blockchain architectures should be developed to support high levels of concurrency and data throughput required by the metaverse platforms. This will require new consensus algorithms, sharding techniques, and other innovations that can improve the performance of blockchain networks. Second, more secure and reliable blockchain-based metaverse platforms are needed. Given the importance of trust and security in virtual environments, it is essential that metaverse platforms be designed with robust security measures in place. This will require new cryptographic techniques, as well as the implementation of best practices for managing private keys and sensitive information.

Third, interoperability standards and protocols must allow different metaverse platforms to communicate and exchange data with each other. This action will enable a seamless and interconnected virtual world in which users can move between metaverse platforms and access a range of services and experiences. Finally, we must explore the potential use cases and business models for blockchain-based metaverse platforms, identifying the most promising applications and industries that could benefit from this technology. This will require decentralized governance models and legal and regulatory frameworks that support the growth of the metaverse ecosystem.

Overall, there is still much work to be done to realize the potential of blockchain-based metaverse platforms. With continued research and development, it is likely that we will see significant progress in this field. Blockchain technology will certainly play a central role in the evolution of virtual worlds and online communities.

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