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Blockchain paradigm in the metaverse

Paradigma blockchain en el metaverso

Paradigma Blockchain no metaverso

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Resumen

La tecnología blockchain actualmente es una tecnología que está siendo muy utilizada en diversos sectores, uno de los campos donde está siendo muy utilizada es el metaverso que es otra tecnología en auge. Estas dos tecnologías están estrechamente relacionadas y juegan un papel esencial en el progreso tecnológico en diversos ámbitos, como la educación, la medicina y el teletrabajo. Por tal motivo, se decidió realizar una investigación que explicara cómo se está aplicando la tecnología blockchain dentro del metaverso. Para realizar esta investigación se utilizó el método Prisma, el cual facilitó realizar una investigación adecuada siguiendo los criterios establecidos. Se consultaron tres bases de datos: Scopus, IEEE Xplore y ACM, en las cuales se aplicaron las cadenas de búsqueda específicas para cada base de datos y se obtuvieron los artículos utilizados para realizar esta revisión sistemática. En este estudio fue posible ampliar los conceptos generales de blockchain y metaverso. Se detalló la estructura de la blockchain y se presentaron otras estructuras propuestas por varios autores, como HCNCT, MIS, FileInsurer y BlockNet. También se abordó el uso de blockchain en el metaverso, describiendo su propósito y cómo se está utilizando para mejorar diversos aspectos, como la seguridad, el almacenamiento de datos, las transacciones y la economía. Asimismo, se exploró el uso actual de Blockchain en tecnologías como NFT y criptomonedas. Finalmente, profundizamos en cómo blockchain es un componente esencial del metaverso, especialmente cuando se trata de la seguridad de los mundos virtuales.

Palabras claves: Cadena de bloques; Metaverso; NFT; Economía; VD; Seguridad.

Abstract

Blockchain technology is currently a technology that is being widely used in various sectors, one of the fields where it is being widely used is the metaverse, which is another booming technology. These two technologies are closely related and play an essential role in technological progress in various areas, such as education, medicine and teleworking. For this reason, it was decided to carry out an investigation which would explain how blockchain technology is being applied within the metaverse. To carry out this research, the Prisma method was used, which facilitated the completion of an appropriate investigation following the established criteria. Three databases were consulted: Scopus, IEEE Xplore and ACM, in which the specific search strings for each database were applied and the articles used to carry out this systematic review were obtained. In this study, it was possible to expand the general concepts of blockchain and metaverse. The structure of the blockchain was detailed and other structures proposed by several authors were presented, such as HCNCT, MIS, FileInsurer and BlockNet. The use of blockchain in the metaverse was also addressed, describing its purpose and how it is being used to improve various aspects, such as security, data storage, transactions, and economics. Likewise, the current use of Blockchain in technologies such as NFTs and cryptocurrencies was explored. Finally, we delved into how the blockchain is an essential component of the metaverse, especially when it comes to the security of virtual worlds

Keywords: Blockchain; Metaverse; NFT; Economy; RV; Security.

Resumo

A tecnologia Blockchain é atualmente uma tecnologia que está sendo amplamente utilizada em diversos setores, um dos campos onde está sendo amplamente utilizada é o metaverso, que é outra tecnologia em expansão. Estas duas tecnologias estão intimamente relacionadas e desempenham um papel essencial no progresso tecnológico em vários domínios, como a educação, a medicina e o teletrabalho. Por esse motivo, decidiu-se realizar uma investigação que explicasse como a tecnologia blockchain está sendo aplicada no metaverso. Para a realização desta pesquisa foi utilizado o método Prisma, que facilitou a realização de uma investigação adequada seguindo os critérios estabelecidos. Foram consultadas três bases de dados: Scopus, IEEE Xplore e ACM, nas quais foram aplicadas as strings de busca específicas de cada base de dados e obtidos os artigos utilizados para a realização desta revisão sistemática. Neste estudo foi possível ampliar os conceitos gerais de blockchain e metaverso. A estrutura do blockchain foi detalhada e foram apresentadas outras estruturas propostas por diversos autores, como HNCT, MIS, FileInsurer e BlockNet. O uso do blockchain no metaverso também foi abordado, descrevendo sua finalidade e como ele está sendo utilizado para melhorar diversos aspectos como segurança, armazenamento de dados, transações e economia. Da mesma forma, foi explorado o uso atual do Blockchain em tecnologias como NFT e criptomoedas. Por fim, investigamos como o blockchain é um componente essencial do metaverso, especialmente quando se trata da segurança dos mundos virtuais.

Palavras-chave: Blockchain; Metaverso; NFTs; Economia; VOCÊ; Segurança.

Introducción

This research analyzes the integration of blockchain technology in the metaverse due to its growing relevance today and the interest it has aroused in the scientific community. Given the abundance of works and studies in these fields, the purpose of this study is to collect and present valuable information in an understandable way, with the aim of sharing the results obtained in this area.

In this section, the concepts of the metaverse and blockchain will be presented to delve deeper into the topic. The following sections will delve into the topic, showing more information about the blockchain, how it is structured and how this technology is used in the metaverse.

1) *Metaverse:* The "metaverse" identified as the latest technological trend with the potential to revolutionize the digital visual perspective in the modern world, a concept that transcends mere technology and enters the realm of human experience and digital creativity.

Its resonance has become even stronger in a world affected by the COVID-19 pandemic (Karunarathna et al., 2023) where the need for meaningful virtual connections and richer online experiences has increased significantly. As most industries move towards digitalization, the metaverse emerges as a promising platform for this transition by offering an immersive three-dimensional (3D) experience for users (Kuru, 2023). As the boundaries between the physical and the digital become more permeable, the metaverse presents itself as the quintessential medium to navigate this intersection. The root of this concept lies in the novel "Snow Crash", where the notion of a parallel virtual world that could be inhabited and explored by digital avatars engaging in recreational and competitive activities was first outlined. Although it seemed like a distant fantasy at the time, technological innovations and the evolution of virtual reality and augmented reality have turned this fantasy into a plausible reality. Considered a disruptive technology for the future of the Internet, companies like "Meta" (formerly Facebook) are dedicated to its development, promoting interaction between the real and virtual worlds (Y. Wang et al., 2022; Zhang, Luo, et al., 2023; Zhang, Mao, et al., 2023). The metaverse is generally defined as a network of 3D virtual worlds, facilitated by the use of virtual reality (VR) and augmented reality (AR) headsets and has an emphasis on social interaction and various future applications (Srinivasan et al., 2023). The metaverse stands out not only for its ability to create attractive 3D virtual environments but also for its emphasis on social interaction. Avatars not only represent people in this space, but also encourage communication and collaboration, giving people the opportunity to experience human connection through digital platforms in a much more immersive way. The feeling of “being there” becomes more palpable as virtual reality and augmented reality technologies continue to evolve. Our perspective on virtual worlds can be extended. A "mirror world" is a three-dimensional virtual environment that reproduces a real-world place or setting (Polys et al., 2022). In this space people may feel the desire to physically explore or alter with the intention of creating something

completely new and original, for example, what is presented in the work (Kuru, 2023) which facilitates the construction of high-fidelity virtual urban metaverse cyberspaces adapted to the community and citizens, where users can be free to explore and interact with the virtual world and create whatever they want. Other recent developments in the Metaverse include the huge online video game industry such as: Roblox, Fortnite and Minecraft. And online games based on blockchain or NFT such as: Axie Infinity, Decentraland and Upland (Cheng et al., 2022). The metaverse is expanding the possibilities of interactive entertainment and the virtual economy. However, its impact goes beyond gaming, finding applications for socially beneficial activities such as education and vocational training (Jansen et al., 2023). The ability to simulate situations and scenarios in a virtual environment can significantly improve the way we learn and acquire practical skills. In short, the metaverse is not just a passing trend; It is a cultural shift that reshapes our relationship with technology and redefines how we interact and create in the digital world. As technologies continue to evolve, the metaverse is becoming fertile ground for innovation, creativity and human connection, impacting not only the way we entertain ourselves but also the way we learn, work and experience. reality itself.

2) *Blockchain:* A term that evokes innovation and transformation, it represents a technology with a scope beyond what its own blockchains could show. Its essence lies in its ability to revolutionize the management and transfer of digital information. It is a technology that allows you to create, store and transfer digital information in a secure, transparent and decentralized way, through the use of peer-to-peer (P2P) networks, cryptography, smart contracts and tokens. Blockchain originated in 2009 with the launch of Bitcoin, ushering in a paradigm shift in the way we understand trust and truthfulness in online transactions (Imperius & Alahmar, 2022). This first decentralized cryptocurrency backed by a proof-of-work based consensus mechanism paved the way for the adoption of blockchain technology and its underlying applications. However, its usefulness goes far beyond cryptocurrencies. Over the

years, blockchain technology has expanded its influence and become a mainstay in a variety of sectors. From finance to supply chain, from insurance to copyright, from healthcare to personal identity (Cao, 2022; Imperius & Alahmar, 2022; Song & Qin, 2022). Blockchain has proven to be a versatile and reliable solution in each of these domains; The essential feature of decentralization supported by blockchain technology has contributed to data security, transparency, and integrity. It's not just about data and transactions; Blockchain is also a crucial foundation for the evolution towards Web3.0, where users regain control over their digital sovereignty (C. Chen et al., 2022). As technology evolves, the possibilities of decentralized applications and the elimination of unnecessary middlemen become more and more real. The essence of Web3.0 is the emancipation of the user by giving them ownership of their data and the ability to interact online without depending on centralized entities. Blockchain is an ingenious structure in which data takes on a new level of security and consistency thanks to the way blocks are interconnected backed by solid foundations. The basis of this architecture lies in the notion of block linking where each block contains a hash that connects to the previous block, thus forging an immutable chain that preserves the integrity of the information over time (Cao, 2022; Hsueh & Chin, 2023; Shao et al., 2023). This feature of immutability grants confidence in the trail of data and transactions, which becomes essential in contexts where veracity and traceability are paramount. The mechanism of this technology is materialized through the network nodes that validate and replicate each transaction and asset in the chain (Imperius & Alahmar, 2022). These nodes function as digital gatekeepers ensuring that the integrity of the chain remains intact and that data cannot be modified without consensus. This is how you build a distributed ledger, which is an accurate, shared representation of transactions that inspires trust (Aria et al., 2023; Huynh-The, Pham, et al., 2023). This ledger, being decentralized and backed by cryptography, becomes a reliable source of information.

An equally intriguing component of blockchain is smart contracts, programs that automatically operate according to predefined rules. These autonomous protocols eliminate intermediaries since they are executed without the need for third parties. This not only streamlines processes but also minimizes human errors and reduces costs (Imperius & Alahmar, 2022; Qin et al., 2023; Singh et al., 2022). The self-executing ability of these contracts opens the door to a variety of applications, from automating agreements to creating transparent and secure voting systems. Furthermore, tokens are another key term in the blockchain field. These units of value have the versatility to represent both physical and digital assets on the blockchain (Song & Qin, 2022). Whether it is a currency, a digital good, or even ownership of a physical asset, tokens enable a unique and transferable representation of value in the digital space (Ritterbusch & Teichmann, 2023; Yilmaz et al., 2022). This feature is integrated into various applications, from creating digital currencies to tokenizing real-world assets.

Blockchain technology is not only an innovation in the way we store and manage data, it also sets a new standard for security in the digital world. Storing data in distributed ledgers instead of centralized databases. This paradigm shift creates a virtual barrier against cyberattacks by distributing information between nodes and eliminating single points of vulnerability. By fragmenting data into blocks and distributing them across the network, hackers are faced with a nearly impossible task: accessing and altering every record in the chain. This decentralization acts as an additional layer of security by increasing confidence in the integrity of the stored data. A critical aspect of blockchain security is its ability to exclude suspicious records and maintain ongoing integrity. This is achieved through its consensus architecture and the validation of transactions by the network nodes (Song & Qin, 2022). Every transaction or modification on the chain requires a majority consensus that prevents malicious or inaccurate records from being introduced onto the chain. This ensures that the chain is maintained as a reliable and accurate record of transactions. Building trust is one of the main

objectives of blockchain and this is achieved through its ability to operate on public or private networks (Hsueh & Chin, 2023). Public networks like Bitcoin and Ethereum validate data through miner competition, ensuring that only verified and agreed upon data is accepted. On the other hand, private networks are established between trusted parties and use pre-established agreements to validate transactions, resulting in greater speed and control. The immutable characteristic of blocks supported by the use of hashes to link them is a fundamental pillar of blockchain security (Hsueh & Chin, 2023). However, it is important to recognize that while blockchain guarantees immutability, it does not necessarily guarantee absolute reliability of the stored data. Erroneous or incorrect information entered into the chain will initially persist, underscoring the importance of accuracy and verification of data entered into the chain.

In summary Blockchain is a disruptive technology that changes the way we manage and transfer data. Based on blockchains linked by hashes, it guarantees security and integrity. It emerged with Bitcoin in 2009 but its impact goes beyond cryptocurrencies. With smart contracts and tokens it allows the automation and representation of assets. Its decentralization and constant validation increase security and trust in the data. In essence, blockchain redefines digital security and information management.

Our contributions in this research are the following:

- ✓ Give an introduction to blockchain and Metaverse topics.
- ✓ Explain the multidimensional structure of blockchain, as well as expose blockchain-based structures proposed by various authors.
- ✓ Research and write up the use of blockchains in the metaverse, including their current use in different areas of the metaverse.
- ✓ We write how the blockchain is used as a security tool in the metaverse.

The rest of this paper is organized as follows: Section II describes the method used in this research and the search process, in Section III we describe the multidimensional blockchain

structure and other proposed structures based on the blockchain structure, in Section IV describes the use of the blockchain in the metaverse, in section V we explain how the blockchain is currently used and what are the different uses it gives it within the metaverse, in section VI we describe how the blockchain is used as a security tool In the metaverse, section VII contains the discussion, future work and conclusions are proposed.

Development

Blockchain structure

A. Multidimensional Blockchain Structure

The “Multidimensional Blockchain Structure” represents an innovation based on perspectives shared by various blockchain technology experts. The concept of blockchain resembles a decentralized digital ledger that, using cryptographic methods, tracks transactions and assets on a secure network (Uddin et al., 2023).This is similar to the notion of splitting transactions across multiple time dimensions in the multidimensional structure, which enhances security and record sharing. The blockchain stores data in a decentralized network through digital signatures comparable to how transactions are stored securely in each temporal dimension of the structure (Ali et al., 2023). This feature ensures that information is difficult to modify without proper authorization. The proposal of an "open distributed blockchain" is reflected in the multidimensional architecture where each temporal dimension acts as an independent and at the same time connected entity (Lian, 2022). The connection between dimensions is ensured through intelligent interconnection supported by a sophisticated routing system. Including hashes in each block also helps ensure the integrity and immutability of data in each dimension. Specific consensus algorithms can increase the reliability of decentralized storage (H. Chen et al., 2022). The multidimensional structure allows each temporal dimension to employ the most appropriate consensus algorithm for its needs, optimizing efficiency and

reliability. Blockchain is essential for creating trustworthy environments (M. Xu, Guo, et al., 2023) is reflected in the multidimensional structure since each temporal dimension contributes to a safe and transparent environment. The full node conception relates to the notion that each temporal dimension in the structure acts as a full node that validates and stores specific transactions (Doe et al., 2023). Blockchain can act as a bridge between physical and virtual worlds to share information and build decentralized economic systems (Lin, Du, et al., 2023). The Multidimensional Blockchain Structure achieves this integration by connecting various temporal dimensions. The categories of authorized and unauthorized blockchains proposed are relevant in the structure, since different temporal dimensions can have variable levels of access and permissions (Ryu et al., 2022). Finally, he highlights that consensus protocols are essential to solve trust challenges in the blockchain (H. Wang et al., 2023). The Multidimensional Blockchain Structure emphasizes the efficiency of consensus algorithms to strengthen the trust and integrity of each temporal dimension. Altogether The "Multidimensional Blockchain Structure" emerges as a proposal that merges the visions of several experts in blockchain technology, addressing current challenges and building a more versatile and secure system. Combining the concepts presented by these authors creates a framework that distributes transactions across time dimensions, leverages specific consensus algorithms, and connects physical and virtual worlds. This structure seeks to overcome the limits of traditional blockchains by providing greater security, efficiency and adaptability in a constantly evolving ecosystem.

B. Other Proposed Structures

Blockchain technology has revolutionized the way transactions are managed and security is ensured in various fields. Below, we delve into several authors' perspectives on alternative blockchain structures by exploring how these innovative approaches could solve the technology's current and future challenges.

"BlockNet" is introduced as an intriguing framework that seeks to overcome the limitations of conventional blockchains through multidimensional data-oriented storage. This architecture introduces nodes with multiple degrees of entry and exit, strengthening the robustness and resilience of the network. The non-elasticity and deformability capability in BlockNet is achieved through spreading gene propagation, adding an additional layer of security and flexibility. Interconnecting nodes with varying degrees of input and output redefines the way relationships between blocks and nodes are conceived (Lv et al., 2022). This enables the development of multi-chain applications and blockchain microservices, creating exponentially more capabilities and possibilities for the blockchain ecosystem.

"FileInsurer" a revolutionary protocol for building a decentralized storage network based on blockchain. With the exponential increase in data in the digital age, this structure presents itself as a powerful solution by allowing storage providers to share unused resources while providing secure and efficient file distribution (H. Chen et al., 2022). The dynamic file locations and insurance scheme implemented in DSN (Decentralized Storage Network) offer demonstrable robustness and guarantee full compensation for losses. The introduction of randomness in the selection of file locations highlights the importance of equitable distribution and prevention of malicious attacks. This structure is capable of achieving scalability and reliability.

Another proposal is based on a structure in which each database in the database layer is mapped to a network of blockchains, creating a system of interconnected blockchains. This multi-layer architecture enables data separation and secure, efficient implementation of transactions (Lian, 2022). Encryption and sequential organization of transactions are essential for the coherent operation of this system. The integration with the cloud data sharing module underlines the need for seamless collaboration between blockchain systems and cloud services.

A unified blockchain-semantic framework in the context of Web 3.0 unites semantic and blockchain ecosystems in a unified architecture (Lin, Gao, et al., 2023). This innovative approach spans multiple layers and technologies addressing information overload and improving interaction efficiency. The integration of blockchain technology into each layer of the system provides transparency, security and decentralization. The incorporation of semantic mechanisms and deep learning-based adaptation highlight the need for greater efficiency in semantic data processing.

Blockchain-based MEC Platform presents a blockchain-based platform aimed at sharing and optimizing resources in the Metaverse. The proposed architecture involving users, MEC servers and blockchain consortium technology, creates an ecosystem where resources are used efficiently and securely (Z. Wang et al., 2022). Dynamic assignment of download tasks and randomization in the selection of file locations contribute to a fair and resilient environment. The Practical Byzantine Fault Tolerance (PBFT) consensus implementation highlights the importance of reliability in constantly evolving metaverse environments.

Blockchain-assisted semantic communication is being explored, highlighting how this structure can catalyze data circulation and economic activities in the Metaverse (Lin, Du, et al., 2023). The use of targeted semantic attacks to improve semantic similarity and the implementation of zero-knowledge proofs reinforce the integrity of the communication. The incorporation of AIGC (Artificial Intelligence and Content Generation) services highlights the need to advance reliable and secure semantic interaction.

With the rise of metaverses, an architecture is proposed that merges blockchain with edge computing technologies, creating a model that combines the reliability of the blockchain with the efficiency of edge computing (M. Xu, Guo, et al., 2023). Network virtualization and efficient allocation of computing tasks offer a versatile and scalable solution for the demands

of emerging metaverses. Collaboration between large and small companies highlights the importance of interconnection in the blockchain ecosystem.

Focused on secure authentication in metaverse environments, an approach that manages user identification data using blockchain technology is presented (Ryu et al., 2022). This framework strengthens security and privacy in emerging metaverses, addressing concerns about digital identity and confidentiality. The implementation of ECC (Elliptic Curve Encryption) and biometric information underlines the need for strong and reliable authentication in an increasingly complex digital environment.

"HCNCT" proposes a new model so that the different blockchains in the Metaverse can exchange digital content and digital assets more securely. To achieve this, it uses interconnected HCNCT chains and adds a notary system that is based on features that make transactions secure and do not depend on a single central entity (Ren et al., 2023). It uses cryptographic techniques such as key sharing and verifiable secrets to protect transactions between different chains. This solves problems that exist in the traditional HTLC method, which has weaknesses against certain attacks and can also rely too much on a centralized entity for verification. Additionally, it includes a way to evaluate user trustworthiness, which decreases the likelihood of malicious people ruining transactions. This ensures that transactions are completed successfully. To ensure the reliability of the notarial system, they also implemented careful management of those in charge of the verification process.

Finally, MIS proposes an identifier management solution for the metaverse (H. Wang et al., 2023). Aiming to eliminate DNS centralization, MIS is based on the consortium blockchain and seeks to overcome storage and latency limitations. The separation of on-chain and off-chain data and the encryption scheme contribute to security and access control. The implementation of a 4-tier architecture on the blockchain underscores the need for a scalable and adaptive structure for the ever-changing metaverse.

This comprehensive analysis offers a panoramic view of proposals that challenge traditional blockchain structures. By exploring a variety of innovative approaches, this article contributes to the understanding and advancement of ever-evolving blockchain technologies by offering potential solutions to emerging challenges in the digital world.

Blockchain in the Metaverse

The concept of Blockchain in the Metaverse represents a critical convergence between innovative blockchain technology and the emerging Metaverse, a digital space that amalgamates elements of the real and virtual world. This convergence is critical to understanding how blockchain technology is shaping the future of the Metaverse and how these two technologies are poised to influence each other in significant ways. Initially, blockchain technology stands out as the backbone of Web3.0, an evolution of the Internet based on principles of decentralization, security and privacy. This has the potential to revolutionize online communication by providing users with greater control over their data and a more secure and confidential experience. The blockchain's ability to safeguard the security of users in the Metaverse is an essential aspect of its adoption (Far et al., 2022). A key aspect of the Metaverse is the convergence with Web3 and technologies such as blockchain. This means that Web3 and the blockchain are intrinsically linked to the development and functioning of the Metaverse. This interconnection further underscores the importance of blockchain technology in creating the Metaverse and its ability to enable a variety of applications and services within this emerging space (Buchholz et al., 2022). From a broader perspective, blockchain stands out as a crucial enabler for the creation of a fair, free and sustainable society within the Metaverse. This new digital space is taking shape as an interactive multimedia community where equity and justice in digital interactions are fundamental. The blockchain becomes an essential tool to ensure that transactions and interactions in the Metaverse are transparent and fair (Duan et al., 2021).

When it comes to economic interactions and transactions in the Metaverse. The Metaverse economy benefits significantly from blockchain technology. The ability to make secure and anonymous transactions as well as the exchange of virtual assets for real-world currency are essential elements of this emerging economy. The blockchain is considered a fundamental infrastructure of the Metaverse as it connects isolated sectors and establishes a solid economic system with transparent and open rules (Yang et al., 2022). Providing the necessary foundation for this economic interaction which integrates the Metaverse into the global economy and creates expansive opportunities for users (Huynh-The, Gadekallu, et al., 2023; H. Xu et al., 2022). The Metaverse benefits from blockchain systems by providing an immersive experience and integrating the virtual world into trusted economic, information and identity systems. This is essential for the Metaverse to become a cohesive and functional space (Tao et al., 2023).

In addition to its economic impact, the blockchain is also used to modernize and personalize operations within the Metaverse. This translates into more efficient industrial development along with the implementation of artificial intelligence to improve the user experience in this constantly evolving environment (Kang et al., 2022; Li et al., 2023). It is important to mention how blockchain is moving into various domains including the IoT environment, automated manufacturing processes, secure data aggregation and mixed reality content sharing (Maksymyuk et al., 2022). The personal experience in the metaverses conceived by companies like Facebook or Microsoft requires detailed representations, realistic interaction between users and natural interfaces (Santos-Torres et al., 2022) which further underlines the importance of blockchain in this context. Artificial intelligence and blockchain are central components in building metaverse models as they help bring these virtual worlds to life in a realistic and dynamic way (Ibrahim et al., 2023).

The blockchain is also used to manage the reputation and participation records of workers in the Metaverse (Jiang et al., 2023). Which guarantees decentralization and transparency in work and community interactions within this space. The decentralized development enabled by the blockchain has facilitated the separation between the client and server sides in the Metaverse, contributing to its sustainability by ensuring decentralization and fairness (Sun et al., 2022). Additionally, it is important to highlight how Web 2.0 and blockchain technology have increased public awareness about privacy and other issues. Blockchain technology together with Web 3.0 has allowed the formation of decentralized autonomous organizations in the Metaverse (Zhao et al., 2022). This improves democratic governance and automates processes through smart contracts, further driving efficiency and transparency within this digital space.

Data management and security are critical considerations in the Metaverse. Blockchains are essential in the development of Web 3.0 and the Metaverse as they can store and validate data about identities and reputations, as well as facilitate the exchange of virtual assets (Doe et al., 2023). This feature is crucial for building a robust and efficient Metaverse. The blockchain offers solutions for the secure and transparent storage of data as well as to guarantee fairness and security in transactions and the storage of resources and data (H. Huang et al., 2022; Truong et al., 2023). This ensures that users can trust the integrity of their data and transactions in the Metaverse. A notable feature of the transition to Web3.0 is that application data is no longer stored in private databases but on open and transparent blockchains (Wu et al., 2023). This returns digital sovereignty to users and gives them greater control over their online information and experiences. Data in the Web3 Metaverse shares the beneficial characteristics of blockchain data: it is open, transparent, tamper-proof, tamper-proof, and traceable (Wu et al., 2023). This gives users confidence that their interactions and virtual assets are protected and verified.

In conclusion, the concept of Blockchain in the Metaverse highlights the importance of blockchain technology in the security, interoperability, privacy and sustainable development of the Metaverse. This integration not only improves user experiences in this ever-evolving space, but also ensures transparency, decentralization, and fairness in their interactions and transactions. Furthermore, it drives technological innovation and the convergence of various technologies in the Metaverse paving the way towards an exciting and promising digital future.

Blockchain in the Present

Blockchain technology is being used in various ways today, its application is very important for various sectors of the metaverse. In this section we will review some of the most important applications of the blockchain within the metaverse.

A. NFT

Non-Fungible Tokens (NFT) have become a highly relevant innovation in the context of blockchain technology. These NFTs representing unique digital units play a crucial role in irrefutable proof of digital asset ownership in the dynamic and expansive Metaverse (Truong et al., 2023). These tokens prized for their unique character and their inability to be exchanged by others occupy a central position in this vast new digital landscape. In an era where the digitization of goods and experiences is common currency, NFTs offer a secure and transparent method to authenticate ownership of digital items, which can range from virtual plots of land to digital artistic creations (Far et al., 2022).

The adoption of NFTs in the Metaverse is based on the inherent ability of blockchain technology to guarantee the integrity of transactions and to maintain an immutable record of the provenance of digital assets (Buchholz et al., 2022). This means that each NFT becomes unquestionable and permanent evidence of ownership in a constantly evolving digital environment. In addition to their main function as proofs of ownership, NFTs have opened new creative and entertainment perspectives in the Metaverse (García R et al., 2023). For example,

digital artists have found in NFTs a platform to display and market their art in virtual galleries, allowing buyers to transparently follow copyright and associated terms of use.

The uniqueness of NFTs is a fundamental distinguishing feature that allows them to accurately and uniquely represent real-world assets in the digital environment of the blockchain (Maksymyuk et al., 2022). This in turn facilitates the transition of these assets into the vast and diverse world of the Internet. This versatility has opened the door to a wide variety of smart contract-based applications and use cases (H. Xu et al., 2022). In short, NFTs and the Metaverse are experiencing an exciting symbiosis that promises a future full of opportunities. NFTs not only act as strong proof of ownership but also play an essential role in creativity, entertainment and authentication in this exciting new and ever-expanding digital environment (Yilmaz et al., 2022).

B. Smart Contracts

Smart contracts are programs stored on a blockchain that are executed when predetermined conditions are met. They are usually used to automate the execution of an agreement so that all participants can be immediately sure of the outcome without the involvement of any intermediary or loss of time. They can also automate a workflow by triggering the next action when conditions are met.

Within the metaverse, smart contracts play an essential role in automating and securing interactions between users, Metaverse service providers (MSPs), and digital content creators. The revolutionary notion of directly incorporating contractual logic into the code, as proposed by Szabo (Wu et al., 2023) in the 1990s it allows automatic execution of the terms of the agreement, eliminating the need for human intervention. Ethereum devised by Buterin took this vision further by presenting a decentralized computing platform that enables the autonomous and transparent execution of programs on the blockchain (Sun et al., 2022). Smart contracts based on specific rules such as the ERC-1155 and ERC-721 standards have expanded

their usefulness in various spheres from the artistic and sports fields to the medical and educational fields (Mohammed & Ralescu, 2023).

This automated, verifiable and transparent process offered by smart contracts is crucial to reducing harmful behavior in the financial system (Huynh-The, Gadekallu, et al., 2023) and provides the opportunity to exchange a diverse range of digital assets on trading platforms (Wu et al., 2023). Smart contracts allow not only the exchange of digital currencies and tokens but also the creation and management of more complex digital assets such as non-fungible tokens (NFTs) that have transformed sectors such as art, entertainment and video games, by allowing authentic limited digital property.

In addition to their role in digital asset management, smart contracts enable an unprecedented approach to copyright and intellectual property management in the metaverse. Examples like CopyrightLY (García R et al., 2023) illustrate how smart contracts can manage authorship claims and license terms in a decentralized environment. Connecting Ethereum smart contracts with decentralized storage systems avoids the prohibitive costs of storing data on-chain, ensuring data integrity and protecting digital assets in metaverse applications (Nguyen et al., 2022).

This innovation takes on particular relevance given the explosion of content and metadata on social media platforms such as Twitter, Facebook or YouTube, where smart contracts can serve as intermediaries connecting the blockchain with off-chain APIs (García R et al., 2023). Together, smart contracts are transforming the way we interact, create and safeguard digital assets in the exciting universe of the metaverse by driving decentralization, reliability and accessibility in this new digital paradigm.

C. Development of Decentralized Platforms

The development of the metaverse as a virtual and decentralized space has been largely driven by blockchain technologies that play a fundamental role in creating decentralized

platforms. To better understand how this has happened, Chaum first introduced the idea of using blockchain in decentralized ledgers, highlighting its resistance to manipulation. This laid the foundation for creating trusted systems of record in the metaverse where information is immutable and tamper-proof, which is crucial to ensuring transparency and trust in a virtual environment. Later, Vitalik Buterin proposed Ethereum, a decentralized platform that uses smart contracts to execute programs autonomously and transparently (Duan et al., 2021). This allowed the creation of decentralized applications (DApps) that operate without intermediaries or centralized authorities. In the context of the metaverse, these DApps have become the building blocks of various experiences and services, from virtual games to digital goods markets.

Along these lines, it is emphasized that the decentralized architecture is crucial to avoid centralization risks, such as the Single Point of Failure (SPoF) (Y. Wang et al., 2023) and to ensure that the system is transparent and controlled in a distributed manner. This means that the metaverse is based on a set of decentralized rules and protocols rather than relying on a single central entity, ensuring equal opportunities for all participants. Additionally, it is important to note how blockchain technologies and decentralization have driven the popularity of digital currencies, such as Bitcoin and other cryptocurrencies (Y. Huang et al., 2023). These digital currencies are used as units of exchange in the metaverse allowing transactions without intermediaries and providing a safe and efficient way to trade and transfer value in this virtual environment.

On the other hand, the importance of allocating dedicated spectrum for public services related to the metaverse (H. Xu et al., 2022). This would allow users to use blockchain technology ubiquitously without relying on centralized operators, ensuring that blockchain infrastructure is available to all participants in the metaverse and encouraging its adoption and development.

In summary, blockchain technology has enabled the creation of decentralized platforms in the metaverse such as Decentraland (Bansal et al., 2022; M. Xu, Ng, et al., 2023) which is a decentralized virtual world that allows users to buy and sell virtual land. Users can create their own microworlds with virtual trees, airplanes and other features. By providing a solid foundation for trusted ledgers, smart contracts, digital asset exchange, and transparent systems. This has driven growth and innovation in the metaverse allowing greater autonomy and equity for its users.

D. Economy

The metaverse economy powered by blockchain technology represents a radical change in the way we think about transactions and digital assets (Truong et al., 2023). Blockchain with its inherent decentralization and transparency allows users to participate in an economic ecosystem without intermediaries, trusting in the security of transactions and the authenticity of digital asset ownership (Y. Huang et al., 2023) such as DeFi which is an emerging financial technology that provides users with a variety of financial services such as loans and investments without third-party authorities such as central banks or financial corporations. Blockchain technology plays a critical role in improving the security and integrity of transactions in the metaverse. Its immutable records ensure that ownership of virtual assets is clear and traceable thereby reducing the risk of fraud and scams in the virtual market. In addition, the transparency provided by blockchain provides users with a complete history of all transactions, which increases trust in the economic system of the metaverse.

In this environment, cryptographic tokens become the universal currency, facilitating not only the acquisition of virtual goods, but also the creation and marketing of original content (Tao et al., 2023). Currently, there are several blockchain-based platforms such as MANA from Decentraland and SAND from Sandbox, which require cryptocurrency tokens to buy and sell virtual assets. Asset tokenization is an essential component in this new economy where virtual

real estate and digital works of art can be divided into fractions, providing diversified investment opportunities (Yang et al., 2022). At the same time, blockchain-enabled smart contracts automate and guarantee the execution of economic agreements by eliminating the need for intermediaries and reducing costs (Y. Wang et al., 2023).

From a more idealistic approach, the metaverse seeks interoperability by allowing users to exchange virtual items between platforms (Yang et al., 2022). The created digital twins as well as native content created by avatars can be transparently managed, uniquely tokenized and monetized using blockchain technology to enable commerce, and blockchain can replace traditional billing systems and open a market for Internet services. of Things (IoT), where users can choose from multiple mobile provider offerings (Maksymyuk et al., 2022).

95% of business executives anticipate that the metaverse will have a favorable influence on their industry over the next five to ten years, and 61% anticipate that it will have a moderate impact on the operation of their company. On the contrary, the economic effect of the potential economic value of the metaverse could reach 5 trillion dollars in 2030 (Bansal et al., 2022). In Conclusion The blockchain-powered metaverse economy promises a transformation in digital transactions and ownership of virtual assets, while improving security and reliability, which represents both a social and economic impact. This shift towards a more inclusive digital future presents significant opportunities for innovation and progress.

Blockchain as a Security Tool in the Metaverse

The metaverse, a concept that encompasses the convergence of advanced technologies such as augmented reality (AR), virtual reality (VR), artificial intelligence (AI) and blockchain technology, is positioned as fertile ground for digital innovation. Creating this vast digital world poses a set of challenges with security and privacy being two of the most crucial aspects to address. In this context, blockchain technology emerges as an essential pillar to guarantee integrity and reliability in the metaverse.

An innovative approach is introduced by proposing the utilization of a cross-chain federated learning framework. This revolutionary approach allows data training to be carried out in a decentralized manner in the metaverse. In addition, it stands out for its ability to preserve user privacy in both physical and virtual environments (Kang et al., 2022). This feat is achieved through a hierarchical blockchain architecture comprising a main chain and multiple subchains. This approach provides an additional layer of security and privacy in an environment where both are essential. Emphasizing the critical role of blockchain in the metaverse as secure and decentralized repositories to store data. The security and privacy of user data are paramount and blockchains guarantee both characteristics (Mohammed & Ralescu, 2023). But its impact is not limited to security; It also acts as a bridge that connects the virtual world of the metaverse with the physical world. This interconnection allows for seamless interoperability between these two domains, creating a more dynamic and efficient metaverse ecosystem. Therefore, it is important to address security in other areas, for example the Internet of Things (IoT) within the metaverse. Therefore, blockchain-based architectures have been proposed (H. Wang et al., 2023) to address identity authentication and privacy protection issues in industrial IoT devices. This perspective underscores the need to consider security from multiple dimensions in the metaverse.

In the context of decentralized applications (DApps), smart contracts are of great importance. These autonomously and transparently executed contracts on the blockchain ensure a fair and equitable environment for operations in the metaverse (Truong et al., 2023). Consensus mechanisms and smart contracts play a crucial role in solving fundamental problems in the metaverse. Consensus mechanisms address the issue of credit in metaverse transactions, while smart contracts provide a trusted and transparent environment for entities participating in the metaverse. These contracts ensure the impartial and unmodified execution of the system rules as described in the contract codes (Yang et al., 2022). This approach

provides a solid foundation for value exchange and economic interaction in the metaverse. Smart contracts serve as guardians of the integrity of DApps, preventing them from being dominated by malicious attackers. This feature aligns with the need for a safe environment in the metaverse. However, the exponential growth in the adoption of blockchain technology has attracted the attention of cybercriminals and hackers. Targeted attacks on blockchains can take various forms, underscoring the urgency to further strengthen security in this environment. The need for robust security systems is evident and the metaverse community is actively seeking innovative solutions to address these risks (Wu et al., 2023). Securing transactions on the blockchain is essential to maintaining the integrity of the metaverse. The underlying blockchain processes a large number of transactions to support the various applications and services in the metaverse (Tao et al., 2023). However, the evolution of security in these transactions is in its early stages and there is ample room for improvements and advancements in this area. The convergence of blockchain with other key technologies has significant potential to elevate the performance and security of the metaverse. The synergy between blockchain, artificial intelligence and virtual reality can strengthen data protection, user authentication and interoperability between various metaverse platforms (Y. Wang & Zhao, 2022).

It is essential to highlight that security and privacy in the metaverse not only apply to data and virtual assets, but also to the management of user identities. The increasing interconnection of devices and users in the metaverse poses challenges in data protection and identity management. Guaranteeing the physical and psychological safety of users becomes a priority in this complex environment (Han et al., 2023). Digital assets in the metaverse are of utmost importance, exposure to risks such as personal information leakage and unauthorized access underlines the need to safeguard virtual assets. Blockchain and non-fungible tokens (NFTs) play an essential role in determining the ownership rights of these digital assets. The traceability and authenticity offered by NFTs reinforce security in asset management in the

metaverse (Y. Huang et al., 2023). An interesting perspective is presented by proposing a blockchain-based proof of concept (PoC) (García R et al., 2023) for copyright management in the metaverse. This allows creators to claim authorship of their content by linking a hash to their work and a timestamp on the blockchain. Additionally, creators can strengthen their claims by adding supporting evidence such as images of the creative process or eyewitness records. This blockchain application not only protects intellectual property rights in the metaverse, but also establishes a reliable infrastructure for digital rights management.

In the context of the metaverse, blockchain technology is emerging not only as an essential security tool but also as a key enabler of numerous aspects of the digital environment. As this virtual world expands and becomes more closely integrated with reality, additional challenges and exciting opportunities present themselves. Augmented reality (AR), virtual reality (VR), artificial intelligence (AI), high-speed networks and cutting-edge computing are of utmost importance; the convergence of these technologies with blockchain technology is essential to guarantee a safe and efficient environment in the metaverse. Furthermore, the need to consider aspects of physical and psychological security is highlighted, especially in health-related applications in the metaverse. This includes protecting users' privacy and securing their medical data in a virtual environment (Bansal et al., 2022). The four must-have features of the metaverse – socialization, immersive interaction, real-world construction, and expandability – not only enrich the metaverse experience, but also introduce security and privacy challenges. Personal information leaks, eavesdropping, unauthorized access, and other risks require constant attention. This is where blockchain technology along with cryptocurrencies and NFTs play a vital role. They certify the unique identity of virtual assets and support the economic security of the metaverse (Y. Huang et al., 2023). Secure computing techniques including blockchains are important tools in a zero trust environment (G. Wang et al., 2022). On a blockchain platform, developers and interested users can establish the provenance of data

through proof of work, proof of stake, or proof of history. In addition to data and virtual asset security, authentication and protection of user identities become even more critical as the metaverse grows. Managing decentralized and secure identities has become a key focus. Blockchain technology can play an important role in verifying identities and managing credentials securely and efficiently (Y. Wang et al., 2023). With the development of blockchain and communication techniques, the Metaverse is considered a promising next-generation Internet paradigm (Si et al., 2022).

In conclusion, the metaverse is a constantly evolving playing field that poses challenges and opportunities in terms of security and privacy. Blockchain technology, along with other innovations, is at the center of efforts to address these challenges and build a secure, reliable metaverse full of possibilities. As the metaverse continues to develop the digital community will continue to explore creative ways to use blockchain technology to strengthen security and privacy in this exciting new digital world.

Methodology

In this study, an exhaustive review of the scientific literature has been carried out that focuses on publications related to Blockchain and its connection with the metaverse. To carry out this work, the guidelines established in the PRISMA statement have been followed (Figure 1 shows the four-level flow diagram used), which ensures the correct execution of the systematic reviews. The production process in its different stages will be described in detail below.

A. Initial Search

It started with an initial search combining the keywords 'Blockchain' and 'Metaverse' in three databases: Scopus, IEEE Xplore and ACM. Subsequently, Boolean operators such as 'AND' and 'OR' were used, and additional terms such as 'Digital Economy', 'Transactions in the Metaverse', 'Virtual Worlds' and 'Augmented Reality' were added. These searches generated a

substantial set of articles, although several of them were noted to be duplicates or of limited usefulness for this review. However, these results provided us with a general understanding of the breadth of the topic.

B. Systematic Search

We began our systematic search in early June 2023 in the Scopus, IEEE Explore, and ACM databases. We limited our results to publications available from 2019 to the current year 2023, and that were freely accessible. To maintain an organized approach to our work, we used the Parsifal tool, which played a key role in planning the study, formulating research questions, defining inclusion and exclusion criteria, and classifying the reviewed articles.

Search strings varied by database, as no single string was suitable for all. The search strings used in each are detailed below:

- In Scopus, we use the following search string: TITLE-ABS-KEY (("Block chain" OR "Metaverse transactions") AND "metaverse") PUBYEAR > 2019 AND OA (all).
- In IEEE Xplore, two search strings were used: 1. ("Block chain" OR "Data" AND "metaverse" OR "virtual world") AND ("digital economy" OR "cryptocurrency" OR "virtual reality" OR "RV"). 2. ("Block chain" OR "Data") AND ("metaverse" OR "virtual world").
- Finally, in ACM, the search string was the following: [All: block chain] AND [All: metaverse] AND [E-Publication Date: Past 5 years].

These searches generated a total of 55 results in Scopus, 83 results when combining both strings in IEEE Xplore, and 316 results in ACM. Before proceeding to the selection of articles, it was necessary to define the inclusion and exclusion criteria.

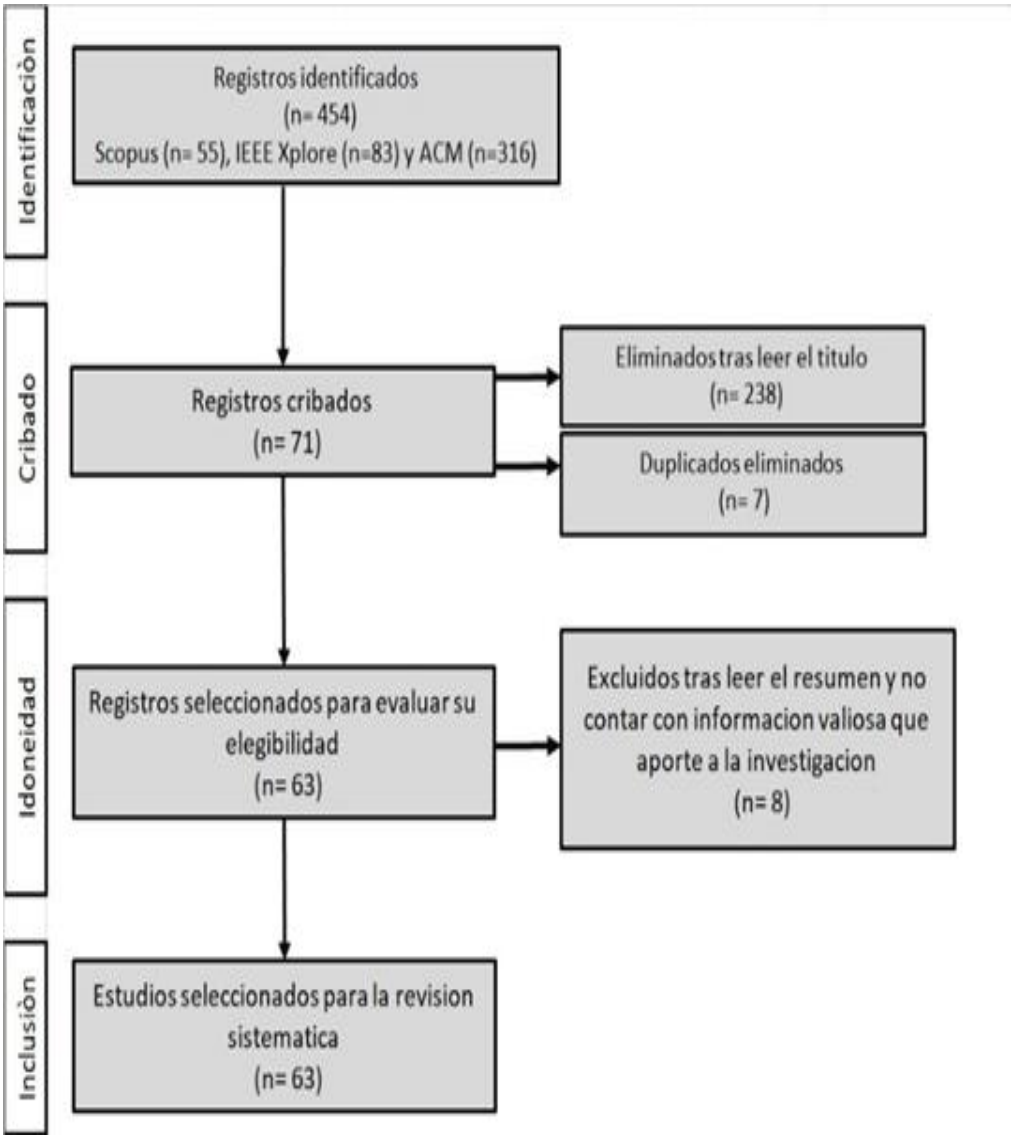

Fig. 1: Prisma flowchart in four levels.

Inclusion Criteria

- That the results found are academic articles.
- The chosen documents must be linked to the field of computing or computer science.
- Only publications with a maximum age of five years will be considered, that is, from 2019 to 2023.

Exclusion Criteria

- Books are excluded.
- Research published before 2019.
- Results whose content is not available in English or Spanish.

According to the established criteria, and with the reading of the title of the results, it was considered appropriate to use 43 results from Scopus, 19 results from IEEE Xplore and 9 results from ACM, after eliminating 7 duplicate results, the summaries of each result and based on this reading, 8 results were discarded since they did not provide greater value to the research and did not have relevant information on the topic. The final selection of the results was made up of 37 articles from Scopus, 19 from IEEE Xplore and 7 from ACM. Finally, 63 documents met the inclusion criteria which were selected to carry out the systematic review. Subsequently, a spreadsheet was created to collect relevant information from the articles, including (Title, Authors, date, Journal, Database, type, abstract, problem, methodology, results, limitations and future work). In addition, the articles were classified into various categories (general blockchain, metaverse blockchain, proposed blockchain, metaverse, metaverse and security). This categorization facilitated the organization and reading of the articles, allowing us to answer the research questions posed. Q1: What is the structure of Blockchain? Q2: What are the types of architecture that Blockchain uses? Q3: What are the applications of Blockchain today? Q4: How can Blockchain be used as a tool for security in the metaverse? Q5: What is the application trend of Blockchain in the metaverse? The articles that were used for this research are distributed between the year 2021, 2022 and 2023 (Figure 2 shows this information in more detail), with a particular emphasis on the year 2023, which contributed the largest number of articles, a total of 34. These articles come from various journals, adding a total of 35 different journals (Figure 3 shows the journals and the number of articles in more detail), where IEEE Access stands out as the one that contributed the most contributions, with a total of 10 items.

Revistas	2021	2022	2023	total
Scopus	1	19	17	37
IEEE Digital Library		7	12	19
ACM Digital Library		2	5	7
	1	28	34	63

Fig. 2: Articles classified by year

REVISTAS	Cantidad de Articulos
2022 IEEE Global Communications Conference, GLOBECOM 2022 - Proceedings	1
2022 IEEE International Conference on Communications Workshops, ICC Workshops 2022	1
IEEE Access	10
IEEE Communications Surveys and Tutorials	2
IEEE Intelligent Systems	1
IEEE Open Journal of the Communications Society	1
IEEE Open Journal of the Computer Society	6
IEEE Transactions on Computational Social Systems	1
IEEE Transactions on Systems, Man, and Cybernetics: Systems	5
IEEE Transactions on Vehicular Technology	1
IEEE Vehicular Technology Conference	1
IEEE Wireless Communications	1
IEEE/CAA Journal of Automatica Sinica	1
Proceedings - 2022 IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems, MASS 2022	1
Proceedings - 2022 IEEE 8th International Conference on Collaboration and Internet Computing, CIC 2022	1
Proceedings - 2022 IEEE International Conference on Blockchain, Blockchain 2022	1
ACM	4
ACM Trans. Multimedia Comput. Commun. Appl.	3
Big Data Mining and Analytics	1
Communications in Computer and Information Science	1
Engineering Applications of Artificial Intelligence	1
Future Generation Computer Systems	1
Future Internet	2
High-Confidence Computing	1
i-com	1
International Conference on Enterprise Information Systems, ICEIS - Proceedings	1
Journal of Mechanics in Medicine and Biology	1
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	1
MM 2021 - Proceedings of the 29th ACM International Conference on Multimedia	1
Mobile Information Systems	1
Nature Machine Intelligence	1
Patterns	1
Procedia Computer Science	2
Proceedings - International Conference on Distributed Computing Systems	1
Sensors	3
SUMA	63

Fig. 3 Articles classified by magazines

C. Manual Search

In this work, a manual search of articles was not used, only the results generated from the queries established in the three selected databases were used.

Resultados

In this work, blockchain and its application in the metaverse were investigated. According to what was said by several authors, interesting results were obtained about the union of these two technologies. Blockchain technology is essential in the creation of the Metaverse said by (Buchholz et al., 2022) since it enables a variety of applications and services within the metaverse. The authors (Duan et al., 2021; Far et al., 2022; Ibrahim et al., 2023; Zhao et al., 2022) They agree that the blockchain is important for the development of the metaverse and the creation of virtual worlds. It was found that the blockchain is widely used in the metaverse and one of the main focuses is data security, as said by (C. Chen et al., 2022) "Blockchain is an ingenious structure in which data acquires a new level of security. The essential feature of decentralization supported by blockchain technology has contributed to the security, transparency and integrity of data." Certainly, blockchain adds a layer of security and privacy to the metaverse data, which is essential in both the real and virtual world, and blockchain guarantees that these characteristics are met (Kang et al., 2022; Mohammed & Ralescu, 2023). Blockchain provides data security and processes a large number of transactions to support the various applications and services in the metaverse, however, what was expressed by (Tao et al., 2023) "The evolution of security in these transactions is in its early stages and there is ample room for improvements and advances in this area." Adding to this (Hsueh & Chin, 2023) says "blockchain ensures immutability, it does not necessarily guarantee the absolute reliability of the stored data. "Error or incorrect information entered into the chain initially will persist, underscoring the importance of accuracy and verification in data entered into the chain." That is to say, this technology still needs to be developed to be able to provide

confidence that the data is completely secure and reliable to use. In order to correct this, blockchain can be used together with other technologies to strengthen data protection, as indicated (Y. Wang & Zhao, 2022) the technologies to be used would be Artificial Intelligence and virtual reality.

Blockchain, apart from security, is also widely used economically according to (Yang et al., 2022) "The blockchain is considered a fundamental infrastructure of the Metaverse as it connects isolated sectors and establishes a solid economic system with transparent and open rules." Several authors also agree that blockchain has proven to be reliable in finance (Cao, 2022; Imperius & Alahmar, 2022; Lin, Du, et al., 2023; Song & Qin, 2022), With the implementation of the blockchain in the metaverse economy, the way we conceive transactions and digital assets changed, a clear example of this is DeFi (Y. Huang et al., 2023) an emerging financial technology that provides users with a variety of financial services such as loans and investments without third-party authorities such as central banks or financial corporations. In addition to this, there are already blockchain-based platforms such as MANA from Decentraland and SAND from Sandbox, which require cryptocurrency tokens to buy and sell virtual assets. When talking about the economy in the metaverse, it is important to mention NFTs (non-fungible tokens).

This technology is important since it provides several benefits, such as determining the ownership rights of digital assets, whether it is a currency, a digital good or even ownership. of a physical asset (Yilmaz et al., 2022), NFT reinforces security in asset management in the metaverse due to its unique character and its inability to be exchanged by others (Buchholz et al., 2022; Y. Huang et al., 2023) In addition, NFTs open new doors to creativity and training in the metaverse (García R et al., 2023) "Digital artists have found in NFTs a platform to display and market their art in virtual galleries, allowing buyers to transparently follow copyright and associated terms of use." NFTs began to gain popularity among the community

to the point of moving large amounts of money with the tokens that were sold, which had a very high sale value, however, as time went by, these tokens began to drop in price and even on certain occasions to be worth nothing, although the NFT market had a big drop, this does not mean that the technology is not important or does not serve in the metaverse, this technology has good foundations and a solid structure which is important to be used in the metaverse.

The blockchain plays a fundamental role in the creation of decentralized platforms which has allowed the creation of DApps decentralized applications (Duan et al., 2021) and it is important to note how blockchain and decentralization boosted digital currencies like Bitcoin and other cryptocurrencies (Y. Huang et al., 2023) in addition to enabling the creation of decentralized platforms in the metaverse such as Decentraland (Bansal et al., 2022; M. Xu, Ng, et al., 2023) a decentralized virtual world that allows users to buy and sell virtual land. Blockchain is fundamental for decentralization, which makes it important for the metaverse.

Finally, the blockchain structure is well established and is currently used, however, this does not stop innovation since the blockchain structure has served to create other types of structures based on the blockchain structure, for example: " "BlockNet" (Lv et al., 2022), "FileInsurer" (H. Chen et al., 2022), HCNCT (Ren et al., 2023), MIS (H. Wang et al., 2023). These proposals for blockchain-based structures propose to improve and fill the gaps in the original blockchain structure. These structures are still in development, some are more established than others, however, there is a lack of research on these structures.

Several limitations were found in the results obtained from which the following future work is proposed:

- Regarding the security of blockchain with respect to data, more research is planned on this topic and on the development of blockchain in the field of security.

- There is a need to further investigate NFTs and their application in metaverse trading and how their situation influences the current market.
- Expand information on the different blockchain-based architectures.

Conclusiones

In conclusion, this research focused on exploring the relationship between blockchain technology and its application in the metaverse, and interesting findings were found supported by various authors. The importance of blockchain technology in the creation and development of the metaverse was highlighted, allowing a wide range of applications and services within this virtual environment. In particular, the crucial role of blockchain in ensuring the security of data in the metaverse was emphasized. Although its contribution to security was recognized, it was also noted that there are still challenges and areas for improvement in the evolution of this technology to ensure the complete reliability of the stored data. In addition to security, the economic impact of blockchain in the metaverse was explored, highlighting its ability to establish solid and transparent economic systems. Blockchain technology has transformed the way digital asset transactions and management are carried out, with notable examples such as DeFi and the rise of NFTs offering greater security and creative opportunities in the metaverse. Blockchain-enabled decentralization was also a key aspect, driving the creation of decentralized applications (DApps) and decentralized virtual platforms such as Decentraland. The blockchain remains fundamental for decentralization in the metaverse. Finally, proposals for blockchain-based structures that seek to improve and expand its original functionality were mentioned. These proposals represent an area of continued innovation that deserves additional research. Taken together, this research underscores the importance and potential of blockchain

technology in the construction and evolution of the metaverse, while recognizing the challenges that must be addressed to make the most of this relationship.

Referencias bibliográficas

Ali, S., Abdullah, Armand, T. P. T., Athar, A., Hussain, A., Ali, M., Yaseen, M., Joo, M. Il, & Kim, H. C. (2023). Metaverse in Healthcare Integrated with Explainable AI and Blockchain: Enabling Immersiveness, Ensuring Trust, and Providing Patient Data Security. *Sensors*, *23*(2). https://doi.org/10.3390/S23020565

Aria, R., Archer, N., Khanlari, M., & Shah, B. (2023). Influential Factors in the Design and Development of a Sustainable Web3/Metaverse and Its Applications. *Future Internet*, *15*(4). https://doi.org/10.3390/FI15040131

Bansal, G., Rajgopal, K., Chamola, V., Xiong, Z., & Niyato, D. (2022). Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare. *IEEE Access*, *10*, 119914–119946. https://doi.org/10.1109/ACCESS.2022.3219845

Buchholz, F., Oppermann, L., & Prinz, W. (2022). There's more than one metaverse. *I-Com*, *21*(3), 313–324. https://doi.org/10.1515/ICOM-2022-0034

Cao, L. (2022). Decentralized AI: Edge Intelligence and Smart Blockchain, Metaverse, Web3, and DeSci. *IEEE Intelligent Systems*, *37*(3), 6–19. https://doi.org/10.1109/MIS.2022.3181504

Chen, C., Zhang, L., Li, Y., Liao, T., Zhao, S., Zheng, Z., Huang, H., & Wu, J. (2022). When Digital Economy Meets Web3.0: Applications and Challenges. *IEEE Open Journal of the Computer Society*, *3*, 233–245. https://doi.org/10.1109/OJCS.2022.3217565

Chen, H., Lu, Y., & Cheng, Y. (2022). FileInsurer: A Scalable and Reliable Protocol for Decentralized File Storage in Blockchain. *Proceedings - International Conference on Distributed Computing Systems*, *2022-July*, 168–179. https://doi.org/10.1109/ICDCS54860.2022.00025

Cheng, R., Wu, N., Varvello, M., Chen, S., & Han, B. (2022). Are we ready for metaverse?: a measurement study of social virtual reality platforms. *Proceedings of the 22nd ACM Internet Measurement Conference, IMC*, *15*(22), 504–518. https://doi.org/10.1145/3517745.3561417

Doe, D. M., Li, J., Dusit, N., Gao, Z., Li, J., & Han, Z. (2023). Promoting the Sustainability of Blockchain in Web 3.0 and the Metaverse Through Diversified Incentive Mechanism Design. *IEEE Open Journal of the Computer Society*, *4*, 171–184. https://doi.org/10.1109/OJCS.2023.3260829

Duan, H., Li, J., Fan, S., Lin, Z., Wu, X., & Cai, W. (2021). Metaverse for Social Good: A University Campus Prototype. *Proceedings of the 29th ACM International Conference on Multimedia*, 153–161. https://doi.org/10.1145/3474085.3479238

Far, S. B., Bamakan, S. M. H., Qu, Q., & Jiang, Q. (2022). A Review of Non-fungible Tokens Applications in the Real-world and Metaverse. *Procedia Computer Science*, *214*(C), 755–762. https://doi.org/10.1016/J.PROCS.2022.11.238

García R, Cediel A, Teixidó M, & Gil R. (2023). Semantics and Non-Fungible Tokens for Copyright Management on the Metaverse and Beyond. *ACM Transactions on Multimedia Computing, Communications and Applications*. https://doi.org/10.1145/3585387

Han, J., Yang, M., Chen, X., Liu, H., Wang, Y., Li, J., Su, Z., Li, Z., & Ma, X. (2023). ParaDefender: A Scenario-Driven Parallel System for Defending Metaverses. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *53*(4), 2118–2127. https://doi.org/10.1109/TSMC.2022.3228928

Hsueh, C. W., & Chin, C. T. (2023). Toward Trusted IoT by General Proof-of-Work. *Sensors*, *23*(1). https://doi.org/10.3390/S23010015

Huang, H., Zeng, X., Zhao, L., Qiu, C., Wu, H., & Fan, L. (2022). Fusion of Building Information Modeling and Blockchain for Metaverse: A Survey. *IEEE Open Journal of the Computer Society*, *3*, 195–207. https://doi.org/10.1109/OJCS.2022.3206494

Huang, Y., Li, Y. J., & Cai, Z. (2023). Security and Privacy in Metaverse: A Comprehensive Survey. *Big Data Mining and Analytics*, *6*(2), 234–247. https://doi.org/10.26599/BDMA.2022.9020047

Huynh-The, T., Gadekallu, T. R., Wang, W., Yenduri, G., Ranaweera, P., Pham, Q. V., da Costa, D. B., & Liyanage, M. (2023). Blockchain for the metaverse: A Review. *Future Generation Computer Systems*, *143*, 401–419. https://doi.org/10.1016/J.FUTURE.2023.02.008

Huynh-The, T., Pham, Q. V., Pham, X. Q., Nguyen, T. T., Han, Z., & Kim, D. S. (2023). Artificial intelligence for the metaverse: A survey. *Engineering Applications of Artificial Intelligence*, *117*. https://doi.org/10.1016/J.ENGAPPAI.2022.105581

Ibrahim, I. F., Morsey, M. M., Mahmoud, A. M., & El-Horbaty, E. S. M. (2023). Towards Developing a Metaverse Authentication Model for Mobile Features. *International Conference on Enterprise Information Systems, ICEIS - Proceedings*, *1*, 691–697. https://doi.org/10.5220/0012039000003467

Imperius, N. P., & Alahmar, A. D. (2022). Systematic Mapping of Testing Smart Contracts for Blockchain Applications. *IEEE Access*, *10*, 112845–112857. https://doi.org/10.1109/ACCESS.2022.3216874

Jansen, M., Donkervliet, J., Trivedi, A., & Iosup, A. (2023). Can My WiFi Handle the Metaverse? A Performance Evaluation Of Meta's Flagship Virtual Reality Hardware. *ICPE 2023 - Companion of the 2023 ACM/SPEC International Conference on Performance Engineering*, 297–303. https://doi.org/10.1145/3578245.3585022

Jiang, Y., Kang, J., Niyato, D., Ge, X., Xiong, Z., Miao, C., & Shen, X. (2023). Reliable Distributed Computing for Metaverse: A Hierarchical Game-Theoretic Approach. *IEEE Transactions on Vehicular Technology*, *72*(1), 1084–1100. https://doi.org/10.1109/TVT.2022.3204839

Kang, J., Ye, D., Nie, J., Xiao, J., Deng, X., Wang, S., Xiong, Z., Yu, R., & Niyato, D. (2022). Blockchain-based Federated Learning for Industrial Metaverses: Incentive Scheme with Optimal AoI. *Proceedings - 2022 IEEE International Conference on Blockchain, Blockchain 2022*, 71–78. https://doi.org/10.1109/BLOCKCHAIN55522.2022.00020

Karunarathna, S., Wijethilaka, S., Ranaweera, P., Hemachandra, K., Samarasinghe, T., & Liyanage, M. (2023). The Role of Network Slicing and Edge Computing in the Metaverse Realization. *IEEE Access*, *11*, 25502–25530. https://doi.org/10.1109/ACCESS.2023.3255510

Kuru, K. (2023). MetaOmniCity: Towards immersive urban metaverse cyberspaces using smart city digital twins. *IEEE Access*. https://doi.org/10.1109/ACCESS.2023.3272890

Li, X., Tian, Y., Ye, P., Duan, H., & Wang, F. Y. (2023). A Novel Scenarios Engineering Methodology for Foundation Models in Metaverse. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *53*(4), 2148–2159. https://doi.org/10.1109/TSMC.2022.3228594

Lian, G. (2022). Blockchain-Based Secure and Trusted Distributed International Trade Big Data Management System. *Mobile Information Systems*, *2022*. https://doi.org/10.1155/2022/7585288

Lin, Y., Du, H., Niyato, D., Nie, J., Zhang, J., Cheng, Y., & Yang, Z. (2023). Blockchain-aided Secure Semantic Communication for AI-Generated Content in Metaverse. *IEEE Open Journal of the Computer Society*, *4*, 72–83. https://doi.org/10.1109/OJCS.2023.3260732

Lin, Y., Gao, Z., Du, H., Niyato, D., Kang, J., Deng, R., & Shen, X. S. (2023). A Unified Blockchain-Semantic Framework for Wireless Edge Intelligence Enabled Web 3.0. *IEEE Wireless Communications*, 1–9. https://doi.org/10.1109/MWC.018.2200568

Lv, Z., Qiao, L., Li, Y., Yuan, Y., & Wang, F.-Y. (2022). BlockNet: Beyond reliable spatial Digital Twins to Parallel Metaverse. *Patterns*, *3*(5). https://doi.org/10.1016/j.patter.2022.100468

Maksymyuk, T., Gazda, J., Bugar, G., Gazda, V., Liyanage, M., & Dohler, M. (2022). Blockchain-Empowered Service Management for the Decentralized Metaverse of Things. *IEEE Access*, *10*, 99025–99037. https://doi.org/10.1109/ACCESS.2022.3205739

Mohammed, S. A., & Ralescu, A. L. (2023). Future Internet Architectures on an Emerging Scale—A Systematic Review. *Future Internet*, *15*(5). https://doi.org/10.3390/FI15050166

Nguyen, C. T., Hoang, D. T., Nguyen, D. N., & Dutkiewicz, E. (2022). MetaChain: A Novel Blockchain-based Framework for Metaverse Applications. *95th IEEE Vehicular Technology Conference - Spring, VTC 2022-Spring*, *2022-June*. https://doi.org/10.1109/VTC2022-SPRING54318.2022.9860983

Polys, N., Roshan, S., Newton, E., Narula, M., & Thai, B. T. (2022). Designing for Social Interactions in a Virtual Art Gallery. *Proceedings - Web3D 2022: 27th ACM Conference on 3D Web Technology*, 1–9. https://doi.org/10.1145/3564533.3564562

Qin, R., Ding, W., Li, J., Guan, S., Wang, G., Ren, Y., & Qu, Z. (2023). Web3-Based Decentralized Autonomous Organizations and Operations: Architectures, Models, and Mechanisms. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *53*(4), 2073–2082. https://doi.org/10.1109/TSMC.2022.3228530

Ren, Y., Lv, Z., Xiong, N. N., & Wang, J. (2023). HCNCT:A Cross-chain Interaction Scheme for the Blockchain-based Metaverse. *ACM Transactions on Multimedia Computing, Communications, and Applications*. https://doi.org/10.1145/3594542

Ritterbusch, G. D., & Teichmann, M. R. (2023). Defining the Metaverse: A Systematic Literature Review. *IEEE Access*, *11*, 12368–12377. https://doi.org/10.1109/ACCESS.2023.3241809

Ryu, J., Son, S., Lee, J., Park, Y., & Park, Y. (2022). Design of Secure Mutual Authentication Scheme for Metaverse Environments Using Blockchain. *IEEE Access*, *10*, 98944–98958. https://doi.org/10.1109/ACCESS.2022.3206457

Santos-Torres, A., Zarraonandia, T., Diaz, P., & Aedo, I. (2022). Comparing Visual Representations of Collaborative Map Interfaces for Immersive Virtual Environments. *IEEE Access*, *10*, 55136–55150. https://doi.org/10.1109/ACCESS.2022.3176949

Shao, L., Tang, W. E. I., Zhang, Z., & Chen, X. (2023). Medical metaverse: Technologies, applications, challenges and future. *Journal of Mechanics in Medicine and Biology*, *23*(2). https://doi.org/10.1142/S0219519423500288

Si, P., Zhao, J., Han, H., Lam, K.-Y., & Liu, Y. (2022). Resource Allocation and Resolution Control in the Metaverse with Mobile Augmented Reality. *GLOBECOM 2022 - 2022 IEEE Global Communications Conference*, 3265–3271. https://doi.org/10.1109/GLOBECOM48099.2022.10001548

Singh, R., Akram, S. V., Gehlot, A., Buddhi, D., Priyadarshi, N., & Twala, B. (2022). Energy System 4.0: Digitalization of the Energy Sector with Inclination towards Sustainability. *Sensors*, *22*(17). https://doi.org/10.3390/S22176619

Song, Y. T., & Qin, J. (2022). Metaverse and Personal Healthcare. *Procedia Computer Science*, *210*(C), 189–197. https://doi.org/10.1016/J.PROCS.2022.10.136

Srinivasan, S., Shippey, S., Aryafar, E., & Chakareski, J. (2023). FBDT: Forward and Backward Data Transmission Across RATs for High Quality Mobile 360-Degree Video VR Streaming. *Proceedings of the 14th Conference on ACM Multimedia Systems*, 130–141. https://doi.org/10.1145/3587819.3590987

Sun, X., Lu, Y., Sun, J., Tang, B., Rehak, K. D., & Zhang, S. (2022). Matrix Syncer - A Multi-chain Data Aggregator for Supporting Blockchain-Based Metaverses. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *13497 LNCS*, 282–293. https://doi.org/10.1007/978-3-031-22061-6_21

Tao, B., Dai, H. N., Xie, H., & Wang, F. L. (2023). Structural Identity Representation Learning for Blockchain-Enabled Metaverse Based on Complex Network Analysis. *IEEE Transactions on Computational Social Systems*, 1–12. https://doi.org/10.1109/TCSS.2022.3233059

Truong, V. T., Le, L. B., & Niyato, D. (2023). Blockchain Meets Metaverse and Digital Asset Management: A Comprehensive Survey. *IEEE Access*, *11*, 26258–26288. https://doi.org/10.1109/ACCESS.2023.3257029

Uddin, M., Manickam, S., Ullah, H., Obaidat, M., & Dandoush, A. (2023). Unveiling the Metaverse: Exploring Emerging Trends, Multifaceted Perspectives, and Future Challenges. *IEEE Access*, 1–1. https://doi.org/10.1109/ACCESS.2023.3281303

Wang, G., Badal, A., Jia, X., Maltz, J. S., Mueller, K., Myers, K. J., Niu, C., Vannier, M., Yan, P., Yu, Z., & Zeng, R. (2022). Development of metaverse for intelligent healthcare. *Nature Machine Intelligence*, *4*(11), 922–929. https://doi.org/10.1038/S42256-022-00549-6

Wang, H., Li, H., Smahi, A., Zhao, F., Yao, Y., Chan, C. C., Wang, S., Yang, W., & Li, S.-Y. R. (2023). MIS: A Multi-Identifier Management and Resolution System in the Metaverse. *ACM Transactions on Multimedia Computing, Communications and Applications*. https://doi.org/10.1145/3597641

Wang, Y., Su, Z., Zhang, N., Xing, R., Liu, D., Luan, T. H., & Shen, X. (2023). A Survey on Metaverse: Fundamentals, Security, and Privacy. *IEEE Communications Surveys and Tutorials*, *25*(1), 319–352. https://doi.org/10.1109/COMST.2022.3202047

Wang, Y., Tian, Y., Wang, J., Cao, Y., Li, S., & Tian, B. (2022). Integrated Inspection of QoM, QoP, and QoS for AOI Industries in Metaverses. *IEEE/CAA Journal of Automatica Sinica*, *9*(12), 2071–2078. https://doi.org/10.1109/JAS.2022.106091

Wang, Y., & Zhao, J. (2022). A Survey of Mobile Edge Computing for the Metaverse: Architectures, Applications, and Challenges. *2022 IEEE 8th International Conference on Collaboration and Internet Computing (CIC)*, 1–9. https://doi.org/10.1109/CIC56439.2022.00011

Wang, Z., Hut, Q., Xu, M., & Jiang, H. (2022). Blockchain-based Edge Resource Sharing for Metaverse. *Proceedings - 2022 IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems, MASS 2022*, 620–626. https://doi.org/10.1109/MASS56207.2022.00092

Wu, J., Lin, K., Lin, D., Zheng, Z., Huang, H., & Zheng, Z. (2023). Financial Crimes in Web3-Empowered Metaverse: Taxonomy, Countermeasures, and Opportunities. *IEEE Open Journal of the Computer Society*, *4*, 37–49. https://doi.org/10.1109/OJCS.2023.3245801

Xu, H., Li, Z., Li, Z., Zhang, X., Sun, Y., & Zhang, L. (2022). Metaverse Native Communication: A Blockchain and Spectrum Prospective. *2022 IEEE International Conference on Communications Workshops, ICC Workshops 2022*, 7–12. https://doi.org/10.1109/ICCWORKSHOPS53468.2022.9814538

Xu, M., Guo, Y., Hu, Q., Xiong, Z., Yu, D., & Cheng, X. (2023). A trustless architecture of blockchain-enabled metaverse. *High-Confidence Computing*, *3*(1). https://doi.org/10.1016/J.HCC.2022.100088

Xu, M., Ng, W. C., Lim, W. Y. B., Kang, J., Xiong, Z., Niyato, D., Yang, Q., Shen, X., & Miao, C. (2023). A Full Dive Into Realizing the Edge-Enabled Metaverse: Visions, Enabling Technologies, and Challenges. *IEEE Communications Surveys and Tutorials*, *25*(1), 656–700. https://doi.org/10.1109/COMST.2022.3221119

Yang, Q., Zhao, Y., Huang, H., Xiong, Z., Kang, J., & Zheng, Z. (2022). Fusing Blockchain and AI With Metaverse: A Survey. *IEEE Open Journal of the Computer Society*, *3*, 122–136. https://doi.org/10.1109/OJCS.2022.3188249

Yilmaz, M., Hacaloğlu, T., & Clarke, P. (2022). Examining the Use of Non-fungible Tokens (NFTs) as a Trading Mechanism for the Metaverse. *Communications in Computer and Information Science*, *1646 CCIS*, 18–28. https://doi.org/10.1007/978-3-031-15559-8_2

Zhang, H., Luo, G., Li, Y., & Wang, F. Y. (2023). Parallel Vision for Intelligent Transportation Systems in Metaverse: Challenges, Solutions, and Potential Applications. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, *53*(6), 3400–3413. https://doi.org/10.1109/TSMC.2022.3228314

Zhang, H., Mao, S., Niyato, D., & Han, Z. (2023). Location-Dependent Augmented Reality Services in Wireless Edge-Enabled Metaverse Systems. *IEEE Open Journal of the Communications Society*, *4*, 171–183. https://doi.org/10.1109/OJCOMS.2023.3234254

Zhao, C., Dai, X., Lv, Y., Niu, J., & Lin, Y. (2022). Decentralized Autonomous Operations and Organizations in TransVerse: Federated Intelligence for Smart Mobility. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*. https://doi.org/10.1109/TSMC.2022.3228914