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SURVEY

Roles of Blockchain in the Metaverse: Concepts, Taxonomy, Recent Advances, Enabling Technologies, and Open Research Issues

MUNA ELSADIG[1], (Member, IEEE), MANAL ABDULLAH ALOHALI[1], ASHRAF OSMAN IBRAHIM[2,3], (Senior Member, IEEE), AND ANAS WALEED ABULFARAJ[4]

[1]Department of Information Systems, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

[2]Creative Advanced Machine Intelligence Research Centre, Faculty of Computing and Informatics, Universiti Malaysia Sabah, Kota Kinabalu, Sabah 88400, Malaysia

[3]Data Science Program, Faculty of Computing and Informatics, Universiti Malaysia Sabah, Kota Kinabalu, Sabah 88400, Malaysia

[4]Department of Information Systems, King Abdulaziz University, Rabigh 21911, Saudi Arabia

Corresponding author: Ashraf Osman Ibrahim (ashrafosman@ums.edu.my)

ABSTRACT The Metaverse platform offers 3D immersive experiences through virtual reality, artificial intelligence, and blockchain technologies. Blockchain-based Metaverse has garnered recent interest due to its decentralization, anonymity, and other security features. Integrating blockchain into Metaverse promotes the formation of a shared ecosystem and provides digital asset tracking, privacy protection, and security in both virtual and physical environments. This paper explores the role of blockchain in creating and managing the Metaverse platform. It is intended to provide a helpful reference for researchers and practitioners in the field of the blockchain-based Metaverse. The main topics covered include the concept and characteristics of the Metaverse; its different use cases, architectures, and technologies; Metaverse as a service provider; Metaverse management; Metaverse users and data; and blockchain-based Metaverse in terms of roles, technologies, applications, and challenges. In addition, recent advances in the blockchain-based Metaverse and challenges such as scalability, interoperability, and edge resource sharing will be discussed. The paper will conclude by highlighting open research issues and future directions, including improving immersion, scalability, security, and integration with existing systems.

INDEX TERMS Blockchain, metaverse, Internet of Things (IoT), big data, cybersecurity.

I. INTRODUCTION

The Metaverse is a new kind of internet application and social structure based on an interconnected platform within cyberspace [1]. The foremost apprehensions about the metaverse are associated with its feasibility and security because a metaverse can consume a spectacular amount of information, data, and computational resources that require a secure and trusted environment.Moreover, security and privacy threats deter the construction of an applied metaverse platform. For example, at the beginning of 2022, the metaverse company Meta was litigated for illegally aggregating facial information without users' permission [2]. In addition, the attack superficial of a metaverse is very largely regarding its diversity.

The emergence of Metaverse technologies derived from blockchain is considered a digital realization that can securely transfigure digital adoption to an astounding level and spread the range of services beyond the standard systems with online access. Using digital twin technology, the Metaverse reflects the real world, securely combines the virtual world and the natural world into an economic system, and generates a blockchain-based ecosystem encompassing many of life's key aspects (e.g. business, healthcare, state systems, education, e-commerce, entertainment, and

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TABLE 1. Metaverse research statistics based on technologies.

Technologies based-Metaverse Research

Technologies	No of papers	No of citation
VR, AR , MR, XR	201	1980
Internet of Things	32	357
Big Data	27	93
Cloud Computing	16	15
Cyber Security	90	955
Blockchain	192	1765
Deep Learning	51	273
Smart Cities	14	319
Digital Twins	40	327
Mobile Intelligence	2	21
Marketplace	11	218
Social Media	19	42

smart industries). Metaverse systems and services have been developed with the resources supplied by digital systems and online storage and processing capabilities at remote data centers and cloud platforms. The focus of Metaverse development has moved towards the consumer experience, with the service's efficiency, performance, and quality as paramount [3], [4]. However, Metaverse platform implementation poses diverse technical challenges. This can include interoperability between applications, technologies, security, privacy, and massive data sharing [4]. Blockchain is one of the most critical technologies applied to Metaverse in order to overcome these challenges, specifically, blockchain's smart contract, which efficiently controls and automates complex operations between Metaverse applications, digital content, services, and users [5]. From a wider perspective, Metaverse platforms are supported by several technologies such as artificial intelligence (AI), big data, internet of things (IoT), virtual reality (VR), augmented reality (AR), multi-reality (MR), andextended reality (XR) [6], [7], [8]. However, Blockchain has multiple capabilities that metaverse applications and technologies have not utilized more widely up-to-date.

A. MOTIVATION AND CONTRIBUTION

Research has been conducted to study the interconnection technologies the Metaverse technology requires. Table 1 presents research statistics for these technologies from 2022 until 30 Jan 2023 [9].

These statistics show Blockchain is one of the most critical pillar technologies enabling Metaverse platform implementation. Several researchers have previously studied Blockchain as a Metaverse enabler, as shown in Table 2, where the specific aspects of metaverse and blockchain-based applications are discussed. However, Blockchain has multiple capabilities that have metaverse characteristics. Architecture, management, applications, and technologies have yet to be efficiently utilized.

The motivation behind this study was the revolutionary potential of blockchain in the dynamic environment of the Metaverse. The Metaverse provides realistic 3D experiences

TABLE 2. Comparative analysis of blockchain impact on metaverse research.

#Ref	Year	Impact of Blockchain for Metaverse Enablers
[10]	2023	-Discuss in detail Blochian based metaverse platforms
[11]	2022	- Explain Blockchain to effectively manage and automate complex interactions among the Metaverse Service Provider (MSP) and the Metaverse users.
[12]	2021	-Discuss in general Blockchain as emerged technologies
[13]	2022	-Explain the concept of blockchain technologies regarding privacy preservation and how it can provide fiddle-proof content sharing amongst Metaverse users
[14]	2022	-A vision of blockchain to provide encrypted address and address-based access model for all users, devices, services in the communication network
[15]	2023	-Merging blockchain and edge computing technologies to combine all the computational resources. -A blockchain aids as fundamental trusted intermediary.
[16]	2022-	- Presented blockchain-based approaches for the metaverse may be used from a privacy and security standpoint. -discuss the technical perspectives of blockchain for metaverse.
[17]	2023	-Focus on Blockchain-based asset storage and service mechanism to metaverse universe: Metarepo." Transactions on Emerging Telecommunications Technologies.
[18]	2023	-Introduced A Taxonomy Characterizing based on Blockchain in metaverse - Empowered Services for the Metaverse.
[19]	2022	- Presented Blockchain and intelligent networking for the metaverse.
[20]	2022	- Conduct an in-depth review of the role and gains of blockchain, intelligent networking, and the combination of both in providing the immersive experiences of the metaverse
[21]	2023	- Introduced Metaverse Taxonomy, components, applications, and open challenges.
This Study	2023	- Discuss metaverse technologies, architecture, management, taxonomy, applications and the impact of Blockchain on all these aspects. - -Develop metaverse architecture and taxonomy-based Blockchain. - Resolve the roles of the blockchain metaverse with cases that demonstrate the significance of incorporating blockchain in the metaverse. - A blockchain aids as a fundamental trusted intermediary. - Discuss Blockchain's technical aspects of all metaverse applications based on Blockchain. - Discuss the opportunities and challenges of metaverse-based Blockchain.

made possible by artificial intelligence and virtual reality. The Metaverse gains decentralization, anonymity, and strong security characteristics by incorporating blockchain. By establishing a shared ecosystem enabled by this combination, security, privacy protection, and tracking of digital assets are made possible in both the virtual and real worlds. The inherent benefits of blockchain technology, such as

TABLE 3. Comparative study of this research with other metaverse surveys.

#Ref	Year	Metaverse Concepts Characteristics	Metaverse Technologies	Metaverse Architecture	Metaverse Management	Metaverse Taxonomy	Metaverse Service Providers and Users	Blockchain Technical Aspects	Blockchain Opportunities and Challenges
[10]	2022	√	√	×	√	×	×	√	√
[11]	2022	×	×	×	√		√	×	√
[12]	2021	√	√	√	√	×	√	√	×
[13]	2022	√	√	√	√	×	×	×	√
[14]	2022	√	×	×	√	×	×	√	√
[15]	2023	√	×	×	√	×	√	√	×
[16]	2022	√	√	√	×	×	√	√	√
[17]	2023	√	√	×	×	×	√	√	√
[18]	2022	√	√	×	×	√	√	×	√
[19]	2023	√	√	√	×	×	×	√	×
[20]	2023	√	√	×	×	×	×	√	×
[21]	2022	√	×	×	×	√	×	√	√
This Study	2023	√	√	√	√	√	√	√	√

transparency, safe data sharing, and data interoperability, can revolutionize the creation and administration of the Metaverse and provide users with a new level of trust and cooperation inside this dynamic virtual world. In order to help researchers and practitioners navigate the rapidly developing field of blockchain-based Metaverse technology, this study clarifies the varied role that blockchain plays in the Metaverse.

The main contributions of this work are shown in table 2 and are summarized below:

- Provide an overview of Metaverse and blockchain, as well as the motivations for using blockchain metaverse. We demonstrate that Metaverse has enormous potential for facilitating blockchain.
- Discuss all taxonomy elements by analyzing the main Metaverse concepts, characteristics, and taxonomy architecture.
- Provide an extensive discussion of the use of blockchain-based Metaverse technologies, which includes blockchain roles, technical aspects, opportunities, and challenges.
- Finally, we discuss several research challenges from the state-of-the-art survey on using Metaverse for blockchain. We also highlight open research opportunities that provide a future research roadmap.

Table 2 shows a variety of research efforts dedicated to integrating blockchain technology with metaverse enablers. Studies have grown in this field over the years, exploring intricate aspects of blockchain applications within the metaverse. The exploration jointly highlights the transformative potential of blockchain in enhancing security, privacy, and functionality within the metaverse. Notably, recent studies, such as [14] and [15], emphasize the fusion of blockchain with edge computing, offering a novel perspective on computational resource optimization. The variety of issues covered is a distinguished feature of these studies. From addressing privacy concerns to suggesting encrypted addressing models and exploring the fusion of blockchain with emerging technologies like edge computing, the studies contribute to a nuanced understanding of the connection between blockchain and the metaverse.

Moreover, a study [17] focuses on blockchain applications within the metaverse for asset storage and service mechanisms in the metaverse universe. They introduced "Metarepo." For Transactions on Emerging Telecommunications Technologies. However, it is crucial to acknowledge these studies' varying depths of coverage. Although some touch upon many dimensions, others focus on specific aspects of the metaverse. This variance underscores the interdisciplinary nature of the topic, with diverse studies emphasizing distinct elements based on their objectives and perspectives.

This paper studies blockchain as an enabler of the Metaverse. First, comparison analysis and related work are conducted and summarized in Table 3. Then, a review of Metaverse concepts, users, service providers, and characteristics will be discussed. Second, a Metaverse taxonomy is presented based on architecture, technology, role as a service provider, management, users, and data. Finally, blockchain-based Metaverse roles, challenges, and opportunities will be discussed. In addition, Table 3 compares the current study with previous metaverse surveys, revealing a comprehensive and balanced approach to understanding the metaverse ecosystem and the role of blockchain within it. The study stands out for its consistent coverage across various dimensions, including metaverse concepts, technologies, architecture, management, taxonomy, users, and blockchain. Unlike previous studies that show gaps in coverage, this study provides a holistic understanding of the metaverse. It balances by addressing technical and non-technical dimensions, confirming in-depth topic exploration. This inclusivity is mainly evident in the study's thorough discussion of the opportunities and challenges of integrating blockchain into the metaverse.

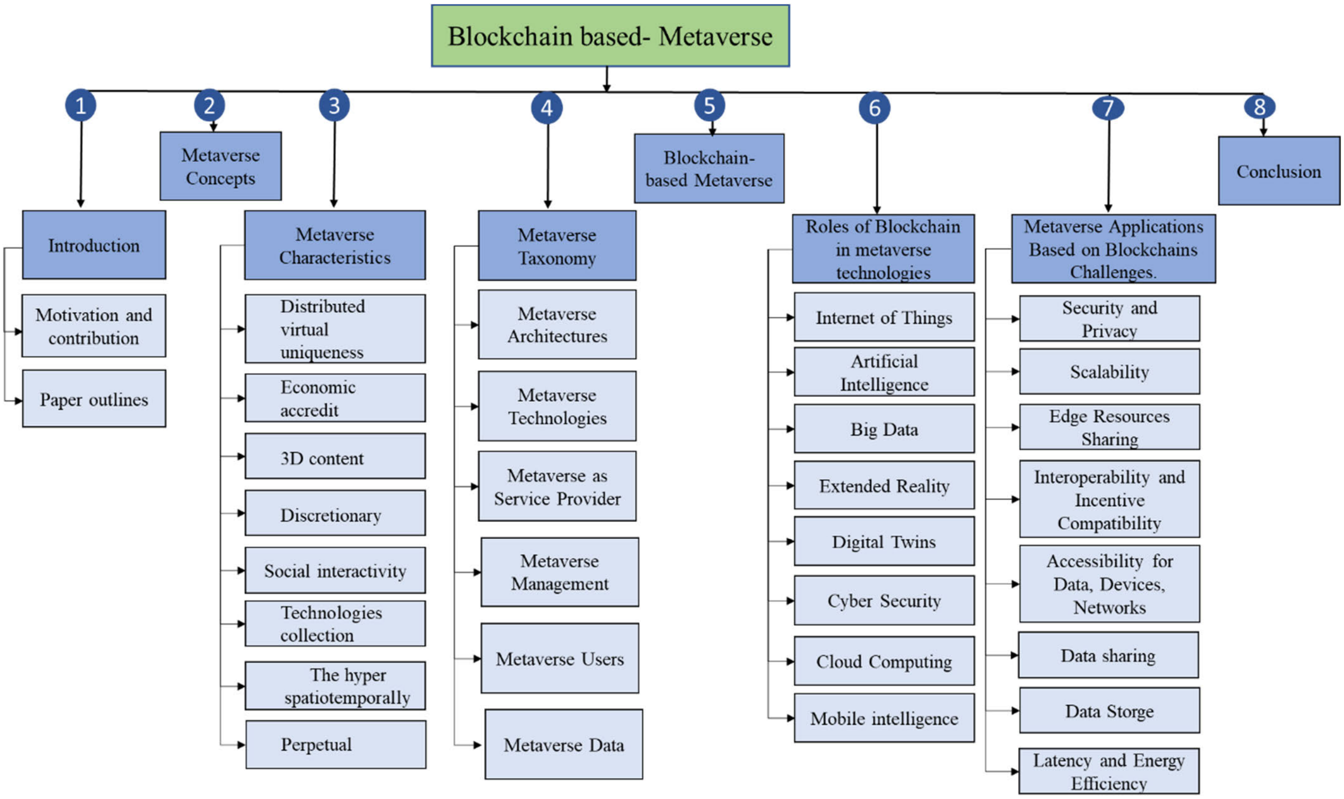

FIGURE 1. Road map of the paper's sections.

B. PAPER OUTLINES

The paper is organized as follows: Section II introduces metaverse concepts, Section III shows metaverse characteristics, Section IV presents metaverse taxonomy, Section V offers blockchain-based metaverse, Section VI discusses the roles of blockchain in metaverse technologies, Section VII provides metaverse applications based on blockchain challenges, and Section VIII presents concluding remarks. Figure 1 provides a summary of the paper's organization.

II. METAVERSE CONCEPTS

From a linguistic perspective, the term "Metaverse" consists of two parts: the prefix "meta" which means far or beyond, and the second term "verse," which refers to the concept of the universe. The term Metaverse has come to describe innovative social systems within a novel digital living space, a beyond-reality universe, and a permanent and cohesive diverse-users environment combining physical reality with digital virtuality [21], [22], [23], [24]. From a technical perspective, Metaverse is an innovative internet application that provides human communication and interaction where new technologies emerge within an era of internet-based social interaction [25], [26]. From a business-related perspective, Metaverse has revealed promising business opportunities. Massive corporations, like Facebook in 2021, have committed themselves to creating the Metaverse as a new capital export. User expectations of the freedom of the virtual world, the content, and the internet's interaction methods, among other things, are continually rising [11], [27].

Several Technologies are involved in creating the Metaverse platform, such as virtual reality, IoT, and blockchain, which enable users to take part in many applications in real-time and in parallel. In his famous science fiction novel Snow Cras, Neal Stephenson first introduced the concept of Metaverse in 1992 [28]. In Stephenson's novel, users exploit digital avatars to operate and compete to enhance their status.

Arguably, the most crucial consideration in the Metaverse is the economic system, where the token economy is established using blockchain [29]. Blockchain is the foundation technology of digital cryptocurrency, considered the main currency among commercial organizations in the Metaverse space. Therefore, Metaverse characteristics, technologies, architecture, service providers, and users will first be analyzed. Figure 2 shows the concepts of Metaverse.

III. METAVERSE CHARACTERISTIC'S

Metaverse is an internet application that virtually connects diverse technologies with social interactivity. This section provides the key characteristics of Metaverse, and Figure 3 illustrates these characteristics, which can be summarized as follows:

A. DISTRIBUTED VIRTUAL UNIQUENESS

In the Metaverse, users distribute their virtual identity because they must move across multiple systems and applications with different accounts that record only some of their personality characteristics and information. This virtual identity is genuine, autonomous, and has its own roles in different applications [30]. In the Metaverse, third parties are avoided for activity management. Users can spontaneously and openly articulate the Metaverse rules, endlessly convey their views, and present themselves. Metaverse gives users a unique custodian of their data and digital identity based on blockchain confidentiality and privacy techniques [31].

B. ECONOMIC CREDIT

The Metaverse introduces an encouraging arena for economic purposes. Opportunities exist for legislators to set trade rules for web3 technologies that maintain user security and stimulate innovation. These rules should encourage greater collaboration between public and private industries. The critical components for making the Metaverse an economic success are interoperability and portability, cryptocurrencies or crypto exchanges, and financial services adopted by blockchain methods. In addition, blockchain has broad non-financial applications inspired by the Metaverse economy [32], [33].

C. 3D CONTENT

Metaverse is an internet-based 3D creation featuring virtual territory and physical objects. In the future, users can act remotely, tour virtual museums, and attend virtual festivals at home. Organizations and businesses use innovative technologies such as big data, blockchain, XR, MR, AR, VR, 3D modernization, AI, and IoT to control the 3D Metaverse [7], [34].

D. DISCRETIONARY

The Metaverse operates over various multifaceted physical environments. In particular, heterogeneous hardware may vary in the user interface, data format and classes, data processing, communications, and application services, which drives the need for Metaverse to handle diverse environments flexibly and with discretion. In addition, interaction terminals should be continuously compatible with connected persistent devices [35].

E. SOCIAL INTERACTIVITY

The Metaverse is primarily an environment for social interaction where users play roles and connect in real time utilizing avatars. It has a modern form of social standards. Metaverse has its representative system, legal system, economic formation, and culture, which are close to but not equal to the real world [36].

F. TECHNOLOGIES COLLECTION

Innovative and trending technologies are integrated into the Metaverse platform, which implements blockchain to build an economic system and offers an immersive experience based on VR, AR, and MR technology. Metaverse uses digital twin technology to create a mirror image of the real world, and it collects, shares, and stores data using IoT, big data, and cloud computing [37].

G. HYBER SPATIOTEMPORALLY

Metaverse encourages the virtual and physical worlds to coexist. It transcends the confines of time and location and offers consumers unrestricted, cost-free, immersive experiences [38].

H. PERPETUITY

The Metaverse platform was developed to be sustainable and perpetual. Moreover, the evolution and upgrading of Metaverse is autonomously accomplished. The appearance of the Metaverse is due to the evolution of technology and science within the growth of human civilization. It has unique social associations, beliefs, ethical regulations, and industrial society.

The Metaverse is simultaneously perpetual and evolutionary. With the collaborative innovation of artificial intelligence and human inventors, the growth of Metaverse is dynamic. It has been modernized to generate a new lifestyle and to attract users with a superior dimensional experience [39], [40].

IV. METAVERSE TAXONOMY

In this work, we introduce a new taxonomy for the Metaverse environment. Studies [17], [20] have introduced a taxonomy for the Metaverse, which classifies it into five systemic parts: sensors and physical devices, rendering and recognition, scenario generation, technical methods, user interaction, and Metaverse applications. The taxonomy developed in this work has the following systemic categories: architecture, technologies, Metaverse as a service provider, management, technologies, users, and data. The content of each category is specified as presented in Figure 4.

A. METAVERSE ARCHITECTURES

Several architectures for Metaverse have been introduced. Duan et al. [41] present an architecture of three layers: infrastructure, interaction, and ecosystem. Another candidate for Metaverse architecture is proposed by Radoff, who defines seven layers from bottom to top: human interface, decentralization, spatial computing, creator economy, discovery, and experience. This sequence of layers depends on the market's expected value [40]. Based on intelligence networking, Yuchuan Fu et al. introduced a Metaverse architecture that covers the physical and the virtual world [19].

An innovative architecture consisting of three main layers (physical space, enabled technology, and virtual space) is developed here and presented in Figure 5. The physical space layer consists of two sub-layers, the first being the Metaverse service layer, where shared services such as healthcare, education, smart city, and others are provided. The second sublayer is the gateway's smart edges, which contain the specific edges users need to access the Meta-

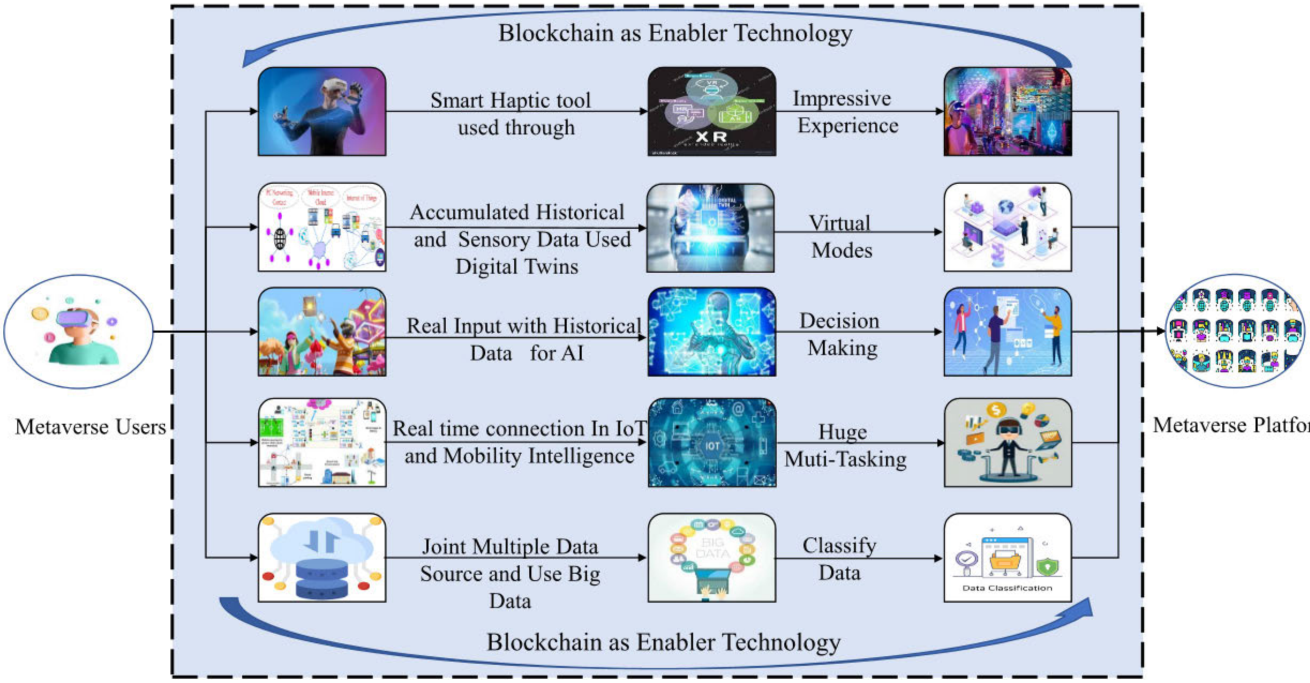

FIGURE 2. Metaverse concepts.

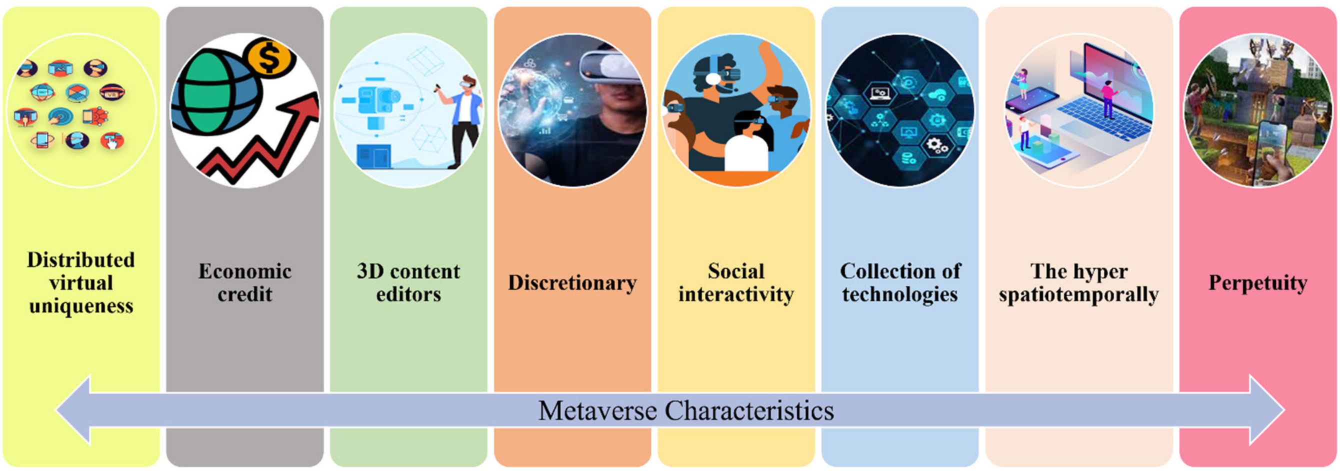

FIGURE 3. Metaverse characteristics.

verse platform, such as wearable haptics, cloud resources, and intelligent mobiles. The second layer in this Metaverse architecture is the enabler technologies, which identify the enabler technologies to transfer from physical space to virtual space, such as AI, DT, and IoT. The final layer is the virtual layer, which encompasses two sub-layers: i) virtual edges, which illustrate the common virtual objects obtained, such as avatars and virtual products, and ii) virtual universe, which the Metaverse platform gives the virtual Metaverse environment.

B. METAVERSE TECHNOLOGIES

The Metaverse platform merges diverse, innovative technologies to achieve user-immersive experiences that connect real and virtual space. These include IoT, blockchain, AI, big data, VR / AR / XR / MR, digital twin, cybersecurity, cloud computing and mobile intelligence. The following sections will discuss the roles of these technologies in the Metaverse platform.

1) INTERNET OF THINGS (IoT)

IoT is a digital network consisting of billions of everyday physical objects interconnected across wired or wireless channels to share information, interact, and access data resources. IoT is an integral part of the Metaverse infrastructure, which controls the link between the physical world and the technological space. The combination of IoT and Metaverse will likely open new opportunities for growth and

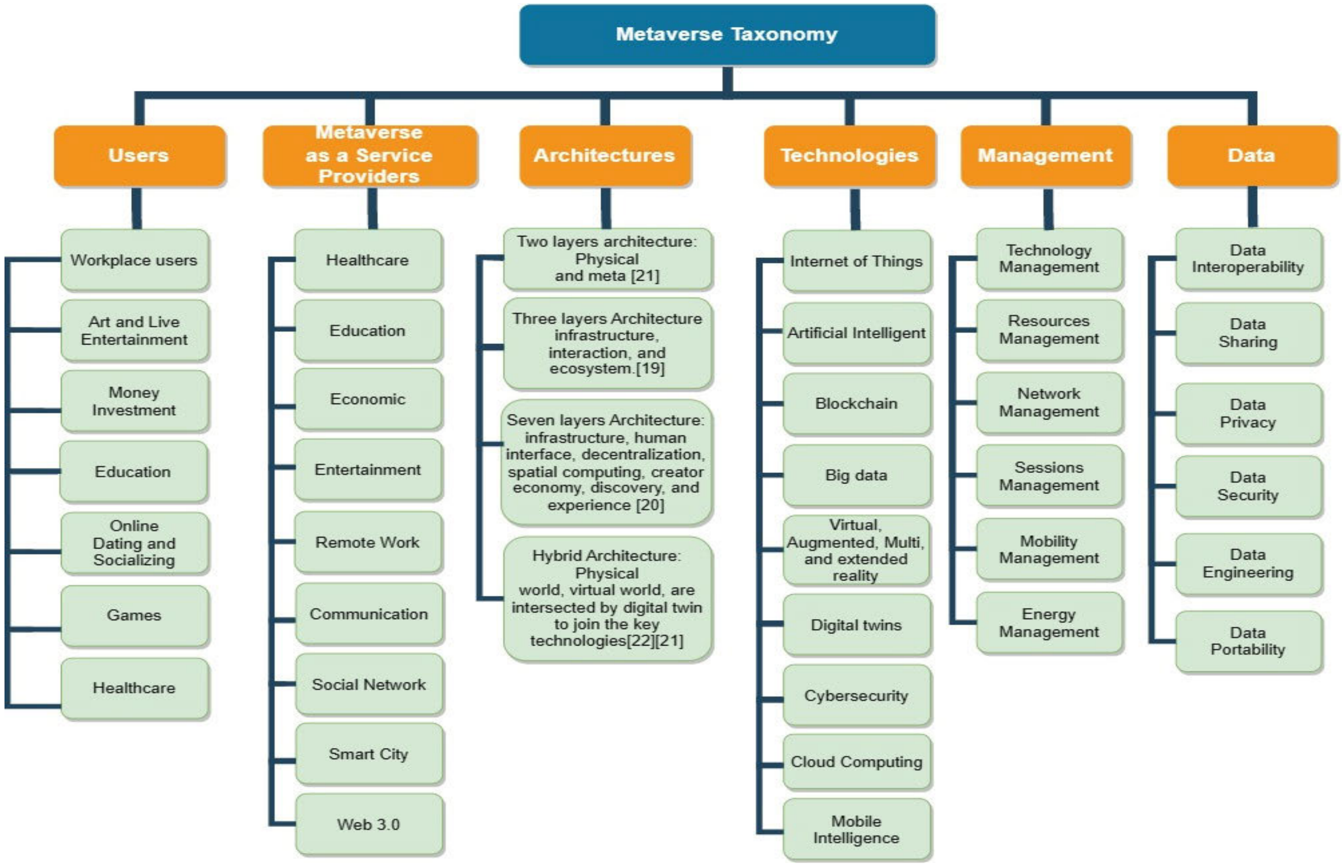

FIGURE 4. Metaverse taxonomy overview.

development within virtual and real space [43]. The real-world data accumulated by IoT devices and sensors is crucial for harmonizing the two worlds [44]. IoT allows the Metaverse to gather information from the real world and immerse it in the virtual one.

Moreover, it is vital to organize this data within the Metaverse and guarantee its security and access for users. Businesses invest substantial amounts of capital on Metaverse projects featuring data intelligence solutions. Figure 6 shows explains IoT in the Metaverse.

2) ARTTIFICIAL INTELLIGENCE

Artificial intelligence, used to integrate intelligence into the Metaverse for a better user experience, is a crucial technology for Metaverse development. An AI simulation built on a genuine image or 3D scan will look at user photographs on the fly and produce incredibly lifelike virtual interpretations known as avatars. The realistic traits and qualities of an avatar in the Metaverse affect the overall quality of the user experience. In more concrete terms, AI may create a variety of facial expressions, emotions, styles, aging-related qualities, and other characteristics for the avatar to make it more animated [45]. As a result, despite linguistic limitations, anyone worldwide will be able to access the Metaverse with significant artificial intelligence training [46].

3) BIG DATA

The Metaverse will reduce the difference between virtual and real-life interaction in the age of big data [40]. All users who navigate the Metaverse work in a data-driven manner with the virtual world. The data will continue to increase as more and more Metaverse applications are developed, resulting in the development of a big data system that will require tremendous processing power. As a result, massive data processing technology is essential for putting the Metaverse into practice [47]. Figure 7 presents the primary operations that big data can process in Metaverse.

4) BLOCKCHAIN

In 2008, Satoshi Nakamoto [48] introduced Bitcoin, the first decentralized digital currency and blockchain technology is now a vital component of the Metaverse platform. Blockchain's distributed and immutable ledger makes transparent transactions possible. Blockchain technology is a model that combines very complex and diverse systems to carry out data exchange, processing, transfer, and storage space. These systems include peer-to-peer networks, cryptographic techniques, communication tools, distributed storage with consistency, and smart contracts. Its greatest strength is the decentralized consensus mechanism used by blockchain to distinguish responsible and anonymous transactions that are successfully suited for the Metaverse [49]. Blockchain is

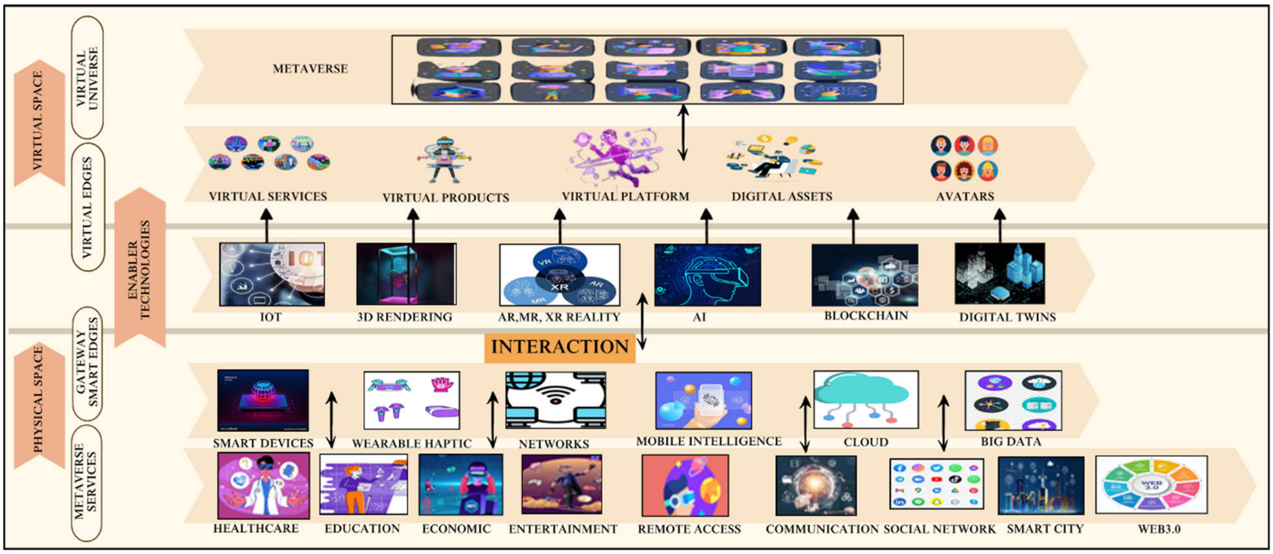

FIGURE 5. Architectural frameworks in the metaverse.

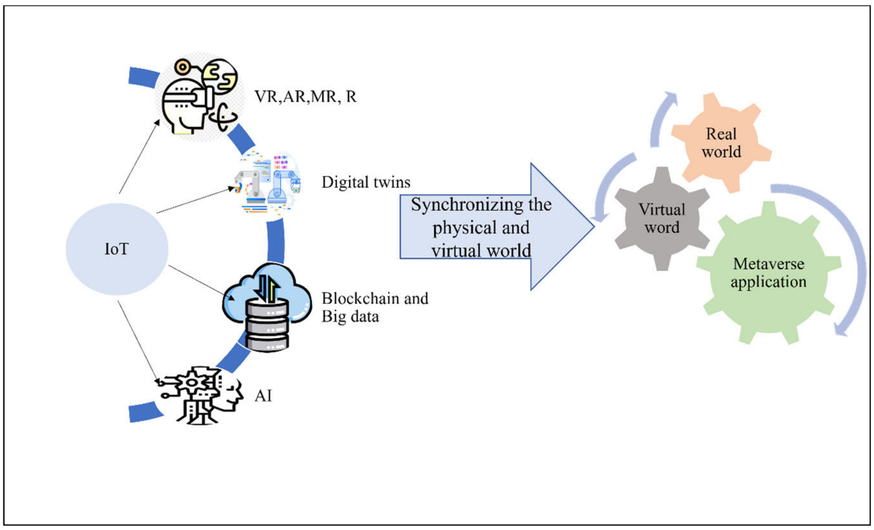

FIGURE 6. Metaverse integration with IoT technology.

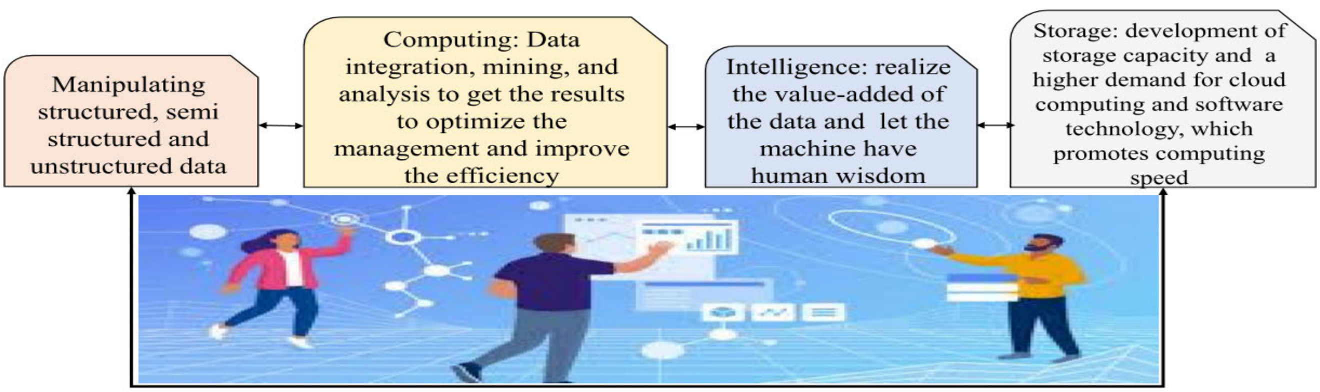

FIGURE 7. Big Data processes within the Metaverse.

a technology facilitator for all Metaverse technologies thanks to these properties. Due to the significant implications of blockchain in the Metaverse, its specific responsibilities will be covered in detail later in this article.

5) VIRTUAL AUGMENTED, MULTI, AND EXTENDED REALITY

The Metaverse platform acquires inputs such as data from participant-managed key elements, whereby the virtual world is created, retained, and improved. AR and VR deliver an immersive 3D experience. AR displays physical space along with additional virtual objects, whereas VR is purely in digital space. AR transforms the environment with digital visuals and fictional characters [50].

It is more accessible than VR and can be used with almost any smartphone or digital camera. A proactive Metaverse is how AR and VR operate. Through physical simulations, VR can improve the Metaverse [51]. Multi-reality (MR) is like AR. However, MR facilitates the location of 3D objects where users can interact with their environment, helping them to add an authentic universe of 3D objects created by computers. Extended Reality (XR) is a technology vital for the Metaverse's growth. Existing AR, VR, and MR mechanisms must be expanded to promote the complete assimilation of virtual objects to a super-realistic level with increased ubiquity. AR, VR, MR, and XR enable users to encounter and become involved in the Metaverse visually.

In contrast, haptics, such as haptic gloves, permit user involvement in the Metaverse using further touch modality [52]. This improves user interactions and opens up the possibility of providing physical services in the Metaverse, such as transmitting a handshake across the globe or virtual remote surgery. These technologies are created by guidelines that promote interoperability, such as the Virtual Reality Modelling Language (VRML), which controls the physics, properties, computer graphics, and interpretation of virtual assets. This allows users to move across the Metaverse easily [53]. Figure 8 shows AR, VR, MR, and XR in Metaverse.

6) DIGITAL TWIN TECHNOLOGY

One of the main enablers of a Metaverse is digital twin technology (DT), which is used to model the physical system virtually in real time [54]. The structure of the Metaverse utilizes DT to twin the real world entirely into a virtual world. The role of DT is achieved through developing and data merging. In [55], researchers found a blockchain-empowered federated learning framework running a trust scheme in Digital Twin for Mobile Networks, which takes direct trust evidence and recommended trust information into account. Their evaluation method can evaluate the trust levels of users with distinctive behavior models accurately. Furthermore, it presents better in avoiding attacks from clients that alternately execute good and bad activities compared with state-of-the-art schemes. The result obtained shows the significance of using secure DW in a metaverse environment-based blockchain.

The Metaverse's pragmatism is combined with DT, which opens up new possibilities for services and social interaction. For instance, Microsoft Mesh allows users operating from several sites to cooperate simultaneously in real-time digital versions of their office. Moreover, digital twins give remote-controlled vehicles and robots better eyesight and coordination while advancing transportation, military, and industrial sectors. Applications like healthcare, education, real estate, and entertainment gain from the prominence of 3D visualization with precision and context awareness [56]. Figure 9 illustrates the digital twin technology in the Metaverse, showing the relationship between physical and digital space.

7) CYBERSECURITY

Implementing Metaverse as a service provider for many industries, applications, and businesses increases cybersecurity threats and risks, where millions of cyber-attacks and malicious activities may occur daily. Therefore, data security in the Metaverse will remain challenging [57], [58], [59]. The main feature of blockchain is immutability, making all Metaverse transaction records unchangeable and enhancing secure sharing capabilities even in an insecure environment. Privacy and security concerns such as network certification theft, personal identity theft, avatar authentication issues, unauthorized data access, phishing attacks, denial of service attacks, misuse of user/avatar data, trusted and interoperable authentication, and ransomware attacks arise due to the technologies that enable the Metaverse (i.e. big data, IoT, blockchain, AR, VR, and DT). Cybersecurity countermeasures have emerged in Metaverse environments [60], [61], [62], [63]. Figure 10 shows various security issues and their corresponding countermeasures. Also shown are the roles of cybersecurity in the Metaverse [64], [65].

8) CLOUD COMPUTING

Developing the Metaverse platform depends upon the growth of cloud computing, whereby computational power may be increased [66]. Moreover, the social and collaborative nature of Metaverse applications results in significant amounts of data being cooperatively and simultaneously disbursed by numerous users [67].

Cloud networks facilitate the end-to-end optimization and dynamic management of exclusively Metaverse applications across Next Generation networks. In Metaverse, high-performance cloud storage, cloud computing, and cloud rendering are required within user devices, along with server reliability, flexibility, and resilience. With cloud computing, Metaverse guarantees continuous rapid processing, complexity reduction, and reduced power consumption [68], [69].

9) MOBILE INTELLIGENCE

The growing number of mobile devices and clients has affected the reality of wireless communication networks, which must progress to handle the specific requirements of superior data speed, latency, and device connection capacity [70], [71]. The emerging Metaverse requires 5G / 6G generational communication networks with specific characteristics. Therefore, Metaverse services and applications need a variety of users to meet this requirement.

5G / 6G networks enhance the working indicators of communication networks by a multiple of up to 100 and also maintain a mechanism for transmitting innovative real-time avatar information and compressed image data created by VR devices and edge cloud servers.

This clearly augments the execution performance of Metaverse technologies that encompass all reality and virtualization. For example, XR devices gather information, including biometric information like fingerprints, handprints, and iris signatures, plus the accumulation of user information from other social media platforms [72], [73], [74], [75]. XR applications can also deliver combined wireless sensors for immersive and real-time user connections. In addition, other Metaverse technologies affected by the exponential evolution of mobile intelligence in internet traffic have led to a remarkable evolution in computing concepts [71]. Intelligent mobile applications have more rigorous demands that cloud computing cannot satisfy, such as ultra-low latency, ultra-high throughput, ultra-high stability, and high spectral efficiency. Meanwhile, big data associated with Metaverse applications and IoT devices contributes to massive growth in overall traffic streams [76].

C. METAVERSE AS SERVICE PROVIDER

Metaverse as a service implies a contribution-based model for using Metaverse platforms instead of acquiring a lifetime authorization. Private, public, and business sectors are now adopting the model of Metaverse as a service provider, which allows different sectors to customize their features and functionalities according to their audiences in a real-time immersive environment. The following sections demonstrate the most common sectors that use Metaverse as a service provider, as illustrated in Figure 12.

1) HEALTH CARE

Recently, healthcare demand has generated an urgent need for digital transformation settings using AI, IoT, telecommunication networks, virtual platforms, and blockchain. In health care, the introduction of Metaverse-connected online space, with the interactive combination of VR, AR, MR, and XR, presents a new era of immersive and real-time experiences to improve social interaction and connection. This technology allows for the conception of virtual environments with 3D space and avatars, which could be significant on patient-adjacent platforms. This technology includes telemedicine platforms, remote operational practices, and simulated medical and surgical education [77], [78]. The execution and acceptance of these emerging virtual healthcare technologies will require complex and innovative methods that guarantee several attributes, which include interoperability between real-world and virtual clinical situations; user-friendliness of the new technologies; efficient compliance with medical issues; health economics; governance, ethics, and cybersecurity [79], [80], [81], [82].

2) EDUCATION

During the COVID-19 period, examples of the mirror world (i.e. video conferencing systems such as Zoom, Webex, Google Meet, and Teams) were used for virtual education delivery. The Metaverse is specified to mimic mirror world function where Metaverse space has a great potential to enlarge the information and roles required for knowledge while showing the real world accurately as if it is a reflection in a mirror [83]. Nevertheless, a shortcoming of virtual education is the difficulty of providing "on-hand" lessons. With additional Metaverse users, data capital can be used to improve AI tutors for customized lessons "on hand" further [84]. A continuous compromise between delivering the required education services and using the Metaverse tools with haptic technology is required. Moreover, practical learning can be achieved through virtual simulation platforms that will reduce the real-world practical learning cost and risk, for example, dangerous surgery simulation [85], [86], [87].

3) ECONOMICS

The Metaverse is an extension of the physical world, and both worlds come together to generate an incorporated ecosystem [32], [87]. The economic systems within the Metaverse are based on Blockchain, which has been developed to carry out economic systems for various sectors, including decentralized finance (DeFi), cryptocurrencies, non-fungible tokens (NFT), the transaction platforms of digital assets, money exchanges, and others [88], [89]. In the upcoming decades, the Metaverse will be a virtual live territory where all users generate a complete supply chain to deliver and utilize digital content cooperatively. To protect the ownership of digital assets, the owners should manage and follow their flow process. Blockchain, as the practicable decentralized infrastructure of Web 3.0, empowers users to market digital assets with transparency and traceability. All stakeholders can manage the ownership of digital assets through the smart contract-enabled Web 3.0 ecosystem and distribute the economic value within the Metaverse [88]. In addition, digital assets are the mechanism to sustain the development of the Metaverse economic system [90], [91].

4) ENTERTAINMENT

Entertainment, which includes movies, virtual concerts, games, and online sports, is currently the most popular Metaverse service. Online multi-sensory interaction between people is the focal point of the Metaverse, which provides virtual "spaces" in which users act and communicate with each other in real-time via digital representation of players or "avatars" [92], [93]. With the increasing requirements for realism in movies, virtual concerts, games, and online sports, AI is applied to computer agents (or non-player characters) to simulate people's intelligent behavior to enhance players' experience [94]. Several characteristics, such as self-control strategy, realistic character animations, lifelike musical con-

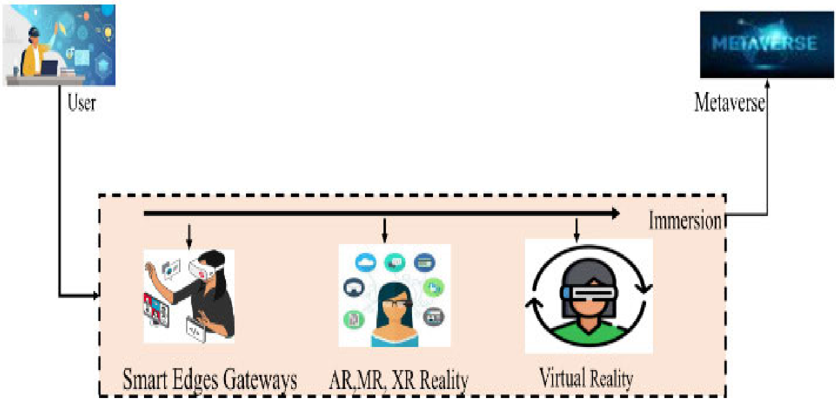

FIGURE 8. Exploring AR, VR, MR, and XR technologies in the metavers.

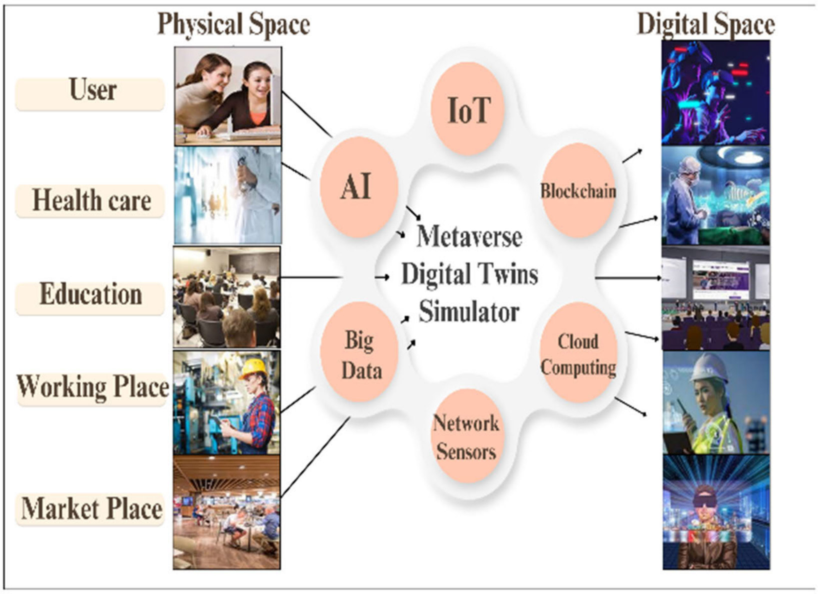

FIGURE 9. The role of digital twins in the metaverse.

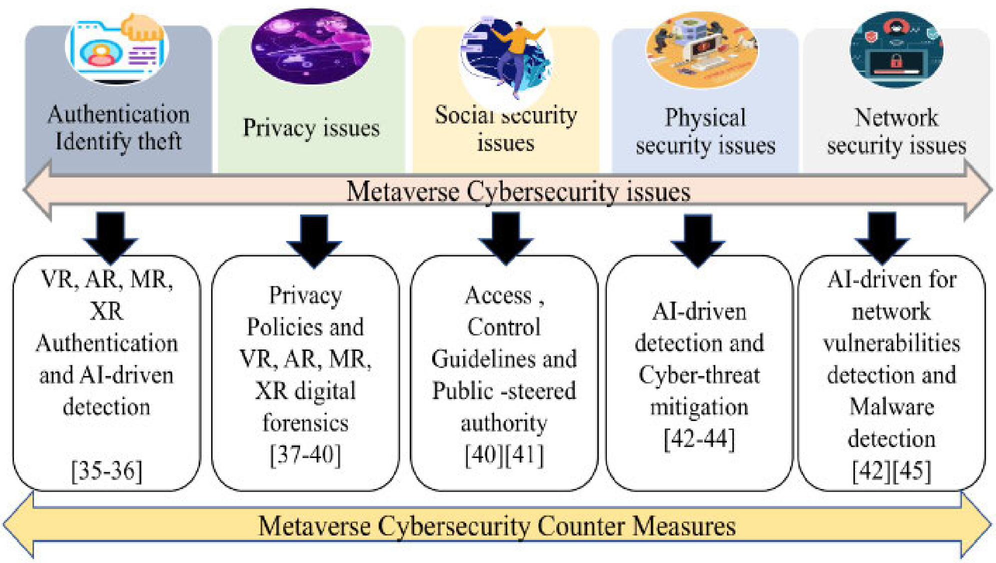

FIGURE 10. Cybersecurity technologies in the metaverse.

cert, superior graphics and voice, and others, exhibit the intelligence of these entertainments [95].

5) REMOTE WORK

Metaverse employee socialization involves immersive job preparation, remote working, and virtual work business meetings. Switching to remote work generates enterprises that prioritize virtual environments [96], [97]. Initial findings show that workers in Metaverses experience excitement from:

1. The spirit, presence, and behaviour of worker avatars,
2. Pragmatism, innovation, and affordances of the virtual environment and
3. Technological steering and resistance.

Smartphones, augmented reality glasses, virtual reality headsets, and PCs can all access this virtual workspace. The Metaverse can adjust how workers cooperate with the technology they use and the people they must cooperate with to carry out their work. The Metaverse potentially augments relations and connections, reintroducing many human aspects into otherwise two-dimensional virtual meetings. It can be considered a step towards a future 3D workplace [98], [99].

6) COMMUNICATION

Communication in the real world is based on distinguishable identities and addresses. However, communication in the Metaverse is different because each user needs a unique identity that fits them. No one can track or verify this identification, which could be an encrypted virtual address in the Metaverse. Reallocating virtual addresses to a person's identity and choosing a specific spectrum to improve address-based communication is necessary to preserve anonymity in the Metaverse. Thus, using blockchain-based Metaverse native communications to connect things to their native encrypted addresses directly could significantly improve current network services based on IP, cellular, HTTP, …etc. [100]. Additionally, without addressing the implementation-related problems with communication and networking, the Metaverse faces a difficult time replacing the Internet, particularly given that it is currently accessible to billions of users. A shift from information to experience-based service communication is generally supported by Metaverse [71], [73], [101].

7) SOCIAL WORKS

Since Facebook's 2021 transformation to a Metaverse platform, a modern era of social interaction has started. Because of the Metaverse, online social networks have become crucial to maintaining social connections. It has had a near-revolutionary impact on the entire social network. The Metaverse is anticipated to make users develop new social service practices. Using Metaverse as a service provider for social networks, a fundamentally new business model depends on three sequential processes: creation, proposition, and value capture [101]. Metaverse provides an integrated stage and collaborative environment for users to design things and integrate. The Metaverse would resemble expanding current social interactions online into 3D or possibly into the real world. Even when people cannot be together physically, it will enable everyone to share immersive experiences. In addition, Metaverse delivers the cognitive and interactive behavior of users in the collaborative design activities in the virtual world [102].

8) SMART CITIES

The smart city concept transforms all city services into digital form, using information technology in city services management. The notion of a smart city has evolved into a Metaverse City. Implementing the Metaverse concept must adapt to various technologies that assist it, for example, VR and AR, loT, AI, internet, and blockchain [103]. These technologies are very beneficial for emerging smart cities to enhance the quality of life, considering sustainability, social objectives, economics, and citizens' luxuries [104], [105].

9) WEB 3.0

Web 3.0 is any technology that relies on blockchain, neural networks, machine learning, AI, IoT, semantic web, cryptocurrency, and VR / AR. Therefore, Metaverse is considered the 3D Internet or Web 3.0 [106], [107] and one of the most feasible technologies to move forward with Web 3.0. Web 3.0, the concept for the next generation of the Internet, embodies the potential for user-centric engagement and interaction experiences in a decentralized manner. Metaverse is becoming one of the most promising technologies to expand Web 3.0 into a three-dimensional virtual environment because it shows potential to support immersive services such as AR / VR, healthcare and education, and remote work [108].

D. METAVERSE MANAGEMENT

Metaverse management refers to the administration, governance, and regulation of virtual world platforms. It involves overseeing the activities and interactions within the Metaverse, including setting rules and policies, handling disputes, and maintaining the technical infrastructure. Metaverse management aims to generate a safe and secure environment for users to engage in virtual experiences while balancing their freedom and enjoyment. The following sections present some critical aspects of Metaverse management, as shown in Figure 11.

1) TECHNOLOGY MANAGEMENT

The most vital technologies for Metaverse management are those for linking and merging real space with virtual space, primarily regarding network, sessions, mobility, and energy management.

2) RESOURCES MANAGEMENT

Within the Metaverse, optimal strategies for digital resource management and diverse objectives task scheduling are necessary. In addition, resource management technology must successfully find and share resources. Researchers are continually investigating resource management solutions to support the Metaverse's implementation in heterogeneous environments and to provide a dynamic resource allocation framework to synchronize the Metaverse with IoT services and data [109], [110]. On the other hand, developers have also introduced cloud resource discovery mechanisms for the Metaverse environment [111].

3) NETWORK MANAGEMENT

In the Metaverse, network and communication techniques make data available to communicate efficiently between partners, overcoming space, time, and service limitations. Moreover, Metaverse applications, technologies, and services in daily life, such as healthcare, education, entertainment, smart cities, and social media, would also be replicated and achieved in the Metaverse [19]. Moreover, methods of networking and communication in the Metaverse must provide secure and error-free data transmission, similar to the role of the network layer in IoT architecture. The most conventional techniques in the network layer incorporate short-range wireless communication and mobile communication technologies, which are also appropriate in the Metaverse for networking and communication [112]. As a universal requirement for wireless data and voice communication, Bluetooth technology provides short-distance wireless connectivity, allowing communication between immovable and mobile devices. These short-range wireless networks are likewise substantial in the Metaverse and will be implemented between devices and "avatars" [113], [114].

4) SESSION MANAGEMENT

Session management technology primarily incorporates technologies significant to security and privacy, and Metaverse should prevent sessions from being attacked. Numerous studies have attempted to develop a defensive technique to avoid destructive authentication threats and encrypt asynchronous sessions, which are applied in the Metaverse environment [115], [116]. In addition, session management addresses the control of communications between users and always available resources over heterogeneous networks. Controlling continuous interactions with dynamic features is essential in the Metaverse scenario, especially when sessions involve many resources. The session environment is accessible to enhance the user's immersion experience in real-time with high-performance levels in 5G and 6G communication wireless networks [117].

5) MOBILITY MANAGEMENT

5G and 6G network technology has provided considerable advantages to people, including superior-speed data transmission with low latency, less cost, huge system capacity, and large-scale device connection. These networks have evolved from centralized mobile cloud computing to distributed fog computing and mobile edge computing (MEC). The merging of MEC with Metaverse technologies and 6G wireless communications addresses the limitations of mobile devices regarding storage space, resource allocation, computational performance, and efficiency [118]. Their revolutionary applications in several domains significantly impact nations, customers, and businesses, leading to a future society of brilliant and autonomous systems that support Metaverse's aims of affording immersive user experiences. However, this makes increasingly greater demands on data communications, transmission, and processing. In addition, MEC runs at the network's edge and is suitable for security-crucial applications. In addition, MEC servers often have a lot of processing power, making them particularly good for Metaverse in analyzing and processing massive volumes of data received by Metaverse applications [119].

6) ENERGY MANAGEMENT

Electric energy consumption is managed and facilitated within the Metaverse architecture. Researchers have introduced several techniques to control energy [13], [120]. The practices developed are based on IoT methods to examine consumption in various efficient and recurrent neural network designs and an exponential power estimate model to decrease power loss and save costs. In addition, another technique is reliant on the theory of harvesting energy and saving electricity by converting the network energy efficiency as an optimization problem into a stochastic problem [121]. The developed techniques applied time-scale energy-sharing algorithms based on the Lyapunov framework [122]. Energy management and sustainability are mandatory in Metaverse and investment challenges.

E. METAVERSE USERS

As the Metaverse continues to grow in popularity and usage, the user demographic will likely expand and diversify, offering opportunities for new and innovative uses and experiences. However, it is also essential to ensure that Metaverse environments are safe, secure, and inclusive for all users, regardless of their background, culture, or identity. The following section will show how Metaverse affects users in many ways, as shown in Figure 13.

1) WORKPLACE USERS

In Metaverse, the development of immersive workspaces enables all workers from anywhere in the world to collaborate and communicate without direct contact. Metaverse can help increase worker productivity, facilitate flexible and customizable workspace, and provide a scalable social environment for businesses and employees. Meanwhile, implementation of the Metaverse faces many limitations, which include worker unfamiliarity with Metaverse technologies and the expense of the platform to build and control [123], [124].

2) ART AND LIVE ENTERTAINMENT USERS

In the Metaverse, users of entertainment services like music, theme parks, festivals, video games, and movies use immersive technology to live together in pleasing virtual reality [125]. For example, VTR concerts by a favorite artist can be experienced from users' homes. The use of augmented and virtual reality to generate effects like holographs can add amazing immersive experiences to concerts. Similarly, users can roam in virtual art galleries, attend festivals, and be in motion technology to produce real-time show performances. Users can play games in groups where digital animation allows them to experience the world and custom app games that feature AR characters and entertainment acts. Users can create exhibitions with rooms featuring live and pre-recorded streams of performances with opportunities for branding and product placements [126], [127], [128].

3) EDUCATION USERS

Education over Metaverse can involve students and teachers in a 3D virtual world. Learners can see and interact with their peers and the surrounding 3D objects, much like in a real classroom [129], [130].

4) ONLINE DATING AND SOCIALIZING

Social media in the Metaverse changes how users consume daily content in the virtual world, where they can act together with digital objects in a shared or private virtual environment that is more immersive and lifelike. On the other hand, the Metaverse social dating platform is an interface between multiple users that facilitates sharing several complex experiences based on avatars. Users can create virtual spaces such as restaurants, park benches, lakes, or parks for real-time sharing [131], [132].

5) GAMES USERS

Gaming in the Metaverse provides a diversity of roles and services highly relevant to users' daily lives. The most famous aspect of video games is 3D virtual games, which extend to users' strong relationships in the Metaverse [133], [134].

6) HEALTHCARE USHERS

The Metaverse can be applied within healthcare in various ways, including training for healthcare professionals and students, surgical procedures, patient experience, and digital twins. Moreover, within the Metaverse, healthcare providers may contact a patient for a regular check-up using a digital twin to explain how a process will be carried out or to envision the effects that their lifestyle preferences might have on the health of their body [77], [78], [79], [134], [135].

F. METAVERSE DATA

In the Metaverse, applications can manipulate the data flow within and across physical and virtual space. Blockchain-based database ledgers address emerging challenges, including data interoperability, sharing, security, privacy, engineering, and portability, as shown in Figure 14. The following section will discuss issues related to Metaverse data [136].

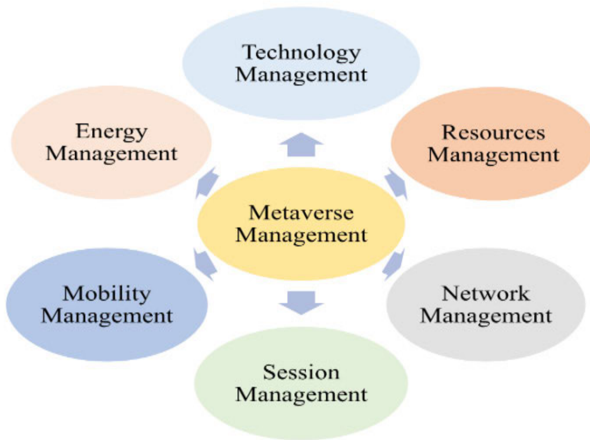

FIGURE 11. Metaverse management strategies.

1) DATA INTEROPERABILITY

In Metaverse, data interoperability is crucial for all innovative Metaverse capabilities. The Metaverse as an ecosystem must control its interoperability from one point to another, where successful virtual spaces require the sustainability of assets at multiple locations [137]. Moreover, organizations require undisrupted business data streams between systems and users, customers, and suppliers. Also, consumers must be confident that their data will be sustained across Metaverse platforms without managing multiple identities [138], [139].

2) DATA SHARING

In the Metaverse, data gathered by one entity must flow effortlessly between different applications, programs, consumers, and boards. Therefore, consumers are granted the ability to move digital assets and avatars between Metaverse platforms. Data-sharing techniques must be established to process multilateral data-sharing arrangements and to satisfy users [106]. In such situations, sharing data between diverse users' including data privacy and protection is challenging [140], [141].

3) DATA PRIVACY AND SECURITY

Organizations can monitor physiological responses and biometric information, including vital signs, facial expressions, and voice inflections, in real time. This sensitive behavioral data must be protected since it is of great value to marketers and advertisers. It is critical to ensure that data is collected ethically and cannot be used for malpractice [142]. In the Metaverse, users can be anyone they want, but it is still essential to protect them. Automated systems must be introduced to protect data privacy and reputation, where updating is vital in reputation management. It is typically done by the Trusted Authority (TA) regularly after aggregation, decrypting, and authenticating a huge number of reputation feedbacks, which leads to excessive computation and communication overheads on the TA lateral and even makes the TA generate the bottleneck of reputation management system in virtual worlds and to prevent users from getting scammed. Therefore, standard regulations must be followed [143], and organizations must be concerned about their data security in all physical and virtual space stages. This includes data ownership, dissemination, storage, processing, tracking, and transition [144].

4) DATA ENGINEERING

Growth in Metaverse usage and innovation is predicted to continue exponentially, with up to 20 times the present data used in 2032 [145]. Therefore, Metaverse providers must adopt diverse solutions to deal with all data transactions and keep track of this massive amount of data. Processing and using this data is challenging because the data stream will become highly speedy, reflective, and extensive [146]. Hence, the Metaverse data platforms must be equipped to cope so that industry owners can accumulate and process internal or third-party data to analyze perceptions, power other industry processes, and keep up with the rapid pace of Metaverse growth.

5) DATA PORTABILITY

Data portability defines how data can be transferred between diverse applications and cloud storage services. Users, businesses, and organizations collect data in the cloud and require the ability to transfer digital assets from one space to another effortlessly. Consequently, data has a financial value, and users must access it wherever they go. Industries using the Metaverse must guarantee the portability of data that will build flexibility for the future [147], [148].

V. BLOCKCHAIN-BASED METAVERSE

Many in the computing industry believe that the Metaverse is the next internet iteration because its social network provides a single, distributed, immersive, continual, 3D virtual space where people can interact beyond the physical world. This innovative technology became widely known when Facebook rebranded itself as Meta in October 2021 and revealed plans to invest at least $10 billion in the concept that year. Over the coming decades, Metaverse will significantly impact technologies such as IoT, big data, 6G, AI, 3D modeling, and reconstruction: VR, spatial computing, and digital twins (DT). However, the most critical technology is blockchain. Widespread applications of the Metaverse are non-fungible tokens (NFTs), digital real estate, video conferences, digital arts, and using Metaverse for work collaboration [149], [150]. Blockchain has crucial roles in Metaverse applications [145], [151], [152]. Firstly, blockchain guarantees data security and privacy through cryptography techniques and consensus protocols.

The Metaverse assembles massive amounts of sensitive information to provide users with the ultimate potential experience without revealing information and in an authentication manner. Second, blockchain guarantees data quality. Since Metaverse collects information from diverse applications such as banking applications, healthcare information systems, governmental services, and entertainment applications, it must examine and validate the quality of this sensitive information. Blockchain offers comprehensive appraisal paths for all transactions, permitting users and organizations to validate and approve all transactions. Thus, it can enhance data quality in the Metaverse [153]. Third, blockchain guarantees data integrity by the mechanism of immutability. Collecting information in a block copy and hashing every block in the chain can only be edited or deleted if all participants approve. Fourth, blockchain guarantees data interoperability for Metaverse's different virtual worlds where stakeholders require data, diverse applications, asset acquisition, and manipulation. There are limitations when interoperating between different applications and data in virtual worlds since they exist in distinct environments, but this is resolved by blockchain's interoperability feature [151], [152].

Moreover, blockchain's other significant features (decentralization, transparency, tamper-proofing, transaction without third-party/fees) provide security, reduced costs, faster performance, scalability, and the efficiency of millions of transactions within Metaverse financial applications. In addition, the smart contract technology used by blockchain guarantees the distribution of the operation of contracts in an automated, autonomous, provable, perceptible, and reliable manner, therefore promoting Metaverse to common use in financial, social, and gaming applications and effectively moderating the destructive and malicious activities that may exist in these areas. Finally, Metaverse technology widely uses non-fungible tokens (NFTs) and federated learning applications where digitization, privacy, decentralization, availability, scalability, and uniqueness features are required. All these features are offered by blockchain [152], [153]. Metaverse's introduction into AI applications requires federated learning (FL), which prevents privacy outflow by allocating training tasks to numerous clients and isolating the local devices from the main server.

Nevertheless, FL has many weaknesses, for instance, single-point failure and malicious data. For the deployment of FL, the benefits of incorporating blockchain technology offer a secure and effective option [147]. However, for NFTs, applications need digital storage and digital data exchange, privacy, security, automation, lower transaction costs, and the verification of participant and owner [147], [155].

VI. ROLES OF BLOCKCHAIN IN METAVERSE TECHNOLOGIES

In the current and future decades, prospective Metaverse applications and consolidated technologies will use the blockchain features of anonymity, security, indisputability, sharing data, privacy, traceability, immutability, decentralization, smart contract, and consensus to accomplish the implementation [146], [152]. In addition, one of the most notable developments in digital innovation and Metaverse financial ecosystems is blockchain technology [156], [157], [158]. Blockchain is a high-impact technology that can modernize finance, economics, gaming, social media, smart cities, entertainment, education, healthcare, and specifically to enable the Metaverse, as presented in Figure 15. Table 4 summarizes the popular applications with case studies based on the specific roles of blockchain that emerged with the pillars of Metaverse and their effectiveness and importance.

A. INTERNET OF THINGS

IoT in Metaverse covers a great range of tasks where massive data from diverse devices in IoT is gathered continuously to guarantee that it functions well across many Metaverse applications. These applications include healthcare, education, and smart cities where huge data, storage, hardware, and physical devices need reliable and secure virtual environments. IoT-based blockchain allows the enormous number of devices in the Metaverse to connect to data within the blockchain, where shared transactions are delivered with corruption-resilient records in virtual worlds. Additionally, IoT data will be accessible to participants and applications without requiring centralized management or control. Blockchain should scale with the Metaverse in IoT, which will be a real challenge.

B. ARTIFICIAL INTELLIGENCE (AI)

AI in the Metaverse is by nature centralized, and the data is managed centrally and accumulated, making it an object for management and exploitation. However, integrity, privacy, traceability, and decentralization of data in blockchain are guaranteed. Therefore, combining blockchain and AI in the Metaverse will help empower trustworthy digital analysis and decision-making on massive data. Moreover, due to the actions of numerous users, diverse and substantial amounts of secondary and tertiary data are produced. This data has a unique identification tag and is utilized as traceable data in the blockchain-based Metaverse. Such information is developing into valuable AI applications within the Metaverse. By contrast, the consensus process in blockchain requires high speeds to add a new block. If a mistake due to any vulnerability is detected in a smart contract, adding a new block will be discouraged, motivating hackers to exploit the vulnerability and losing hundreds of millions of dollars in crypto-currencies. Thus, AI-Agent and federated learning are crucial to correcting and repairing smart contracts, enhancing blockchain application security, regulating active scalability parameters, and delivering operative personalization and authority mechanisms.

C. BIG DATA

Big data management is one crucial technology required to expand Metaverse applications where various data will accumulate to establish a big data network. In fact, with big data, massive data manipulation is crucial to the digital world, which will raise awareness of innovative opportunities in business models within the Metaverse. In contrast, extensive data management in the Metaverse environment must deal with heterogeneous, scalable data with speedy processing requirements. Blockchain in Metaverse will support huge data integrity without the intervention of a third party, high data quality, classified data for users, reduced data retrieval time and cost, and data accessibility.

D. EXTENTED REALITY(XR)

Extended reality (XR) technology combines real and virtual worlds into an environment for human-computer interaction (HCI) using computer technologies and wearables. XR applications are required as an enabler of the Metaverse platform. However, VR, AR, and MR technologies should be improved to fully support the combination of virtual objects for super-realism and enhance its ubiquity. The emergence of XR in the Metaverse raises additional concerns about social and personal issues. Companies can gather huge and sensitive information from diverse XR systems to support their production of innovative and recommended systems. The Metaverse should guarantee the security, privacy, scalability, and transparency of this sensitive information for users of XR systems. Metaverse's blockchain-based distributed ledger would facilitate the authentication and the traceability of XR application data, which would help to create a complementary truthful recommendation system. Additionally, blockchain techniques support data safety and the integrity of XR application file systems.

E. DIGITAL TWINS (DT) TECHNOLOGY

DT in the Metaverse means the modern digitalization of the whole world within the Metaverse. Therefore, all the applications of the Metaverse are unable to work together correctly unless an initial connection between the digital and the physical world is recognized and made. Digital twin applications such as financial markets, healthcare, and social media should collaborate and stay stable in changing virtual environments. Moreover, digital twins must fix consistent communication faults when sharing real-time data. Blockchain techniques provide digital twins in the Metaverse ecosystem, specifically the distributed Hyperledger, which maintains secure data sharing, privacy, and transparency. In addition, all digital twin transactions based on blockchain will be registered and made unchangeable without consensus.

F. CYBERSECURITY

In the Metaverse, data is vital for successfully creating systems by businesses and applications. Due to the management of huge data flows, pervasive user interest profiling, and unequal AI algorithm outputs, the Metaverse may be subject to several security vulnerabilities and privacy attacks. Data storage, data sharing, data portability, data interoperability, and, most importantly, data security and privacy are the fundamental functions of blockchain in the Metaverse. The authentication and access control mechanisms used by the blockchain, and its consensus procedures preserve user data privacy. Blockchain uses hash techniques and asymmetric-key encryption to secure data in the Metaverse. Moreover, the use of blockchain technology to develop a decentralized and transparent-over-domain authentication method for industrial devices is being considered. This scheme will recognize trust between domains and identity-based encryption for device authentication. Additionally, certain accurate domain information is encouraged to be stored off-chain to reduce storage obligations in the blockchain system. An execution of proof-of-concept simulation confirms its reliability and practicability as a consensus protocol in blockchain to ensure privacy protection. For data management security, blockchain guarantees trustworthy data dissemination over Metaverse services, high reliability of data sources, and accurate representation of digital footprints.

G. CLOUD COMPUTING

In the Metaverse, services and systems are expanded to their highest potential with the facilities provided by digital systems and real-time storage/processing capabilities on cloud platforms. Blockchain techniques, specifically peer-to-peer networks, enhance cloud computing-based storage and the processing infrastructure to host Metaverse applications. Edge computing must be used to allow access capacity along with context, secure access control, and location awareness features. Additionally, network slicing can coordinate and build the Metaverse applications stream among all enabler technologies.

H. MOBILE INTELLIGENCE

In the Metaverse, the mobile computing paradigm has evolved by using advanced blockchain, AI, IoT, and 5 / 6 G wireless communications, where distributed fog computing and mobile edge computing (MEC) are merged within the Metaverse platform. MEC drives computer-intensive assignment to the edge of the network and allocates resources as close to the endpoints as possible to overcome the drawbacks of mobile devices, which are limited storage space, high latency, resource optimization, computation performance, high data rate, and efficiency. Based on 6G networks, intelligent mobile devices can be readily networked to leverage blockchain, AI, Metaverse edge computing, and other technologies for data examination and interaction and discharging judgments that allow production to self-organize. In the Metaverse platform supported by blockchain technology, consensus mechanisms based on mining enhance the MEC system's security. In addition, the resource allocation problem can be solved in polynomial time using blockchain technology. Research is therefore concentrated on blockchain-based technologies in the future to address the problem of scarce resources in MEC.

VII. METAVERSE APPLICATION BASED ON BLOCKCHAIN CHALLENGES

Metaverse has enhanced human life by providing expediency and social-economic development. Moreover, the advent of the Metaverse improves social interaction from the perception of technical revolution and collaboration.

Blockchain provides vital techniques for Metaverse development and provision. The fundamental characteristics of Metaverse are realism, hyper-spatiotemporally, sustainability, and heterogeneity. In contrast, implementing Metaverse applications based on Blockchain faces numerous challenges, which are addressed and explained in the following subsections.

A. SECURITY AND PRIVACY

In the Metaverse, users and professionals are concerned with evolving Metaverse security, threats, and risks, which can include Blockchain and smart contracts; decentralization; fraud, phishing, and social engineering; identity theft and cybercrime; privacy, compliance, and ethics; non-fungible tokens; and AI incorporated with virtual and augmented reality.

Metaverse spaces are the most crucial areas of concern, and they relate to the future security of property and privacy from the perspective of the most related security technologies: Blockchain security, IoT cloud services and big data security, interactive technology security, AI security, and digital twin security. In privacy, the most critical issue associated with Blockchain in Metaverse privacy is the crisis of multiple addresses. The system developer can create a cluster of all addresses associated with the same user.

B. SCALABILITY

Since Metaverse is a comprehensive internet transition, scalability is a critical technical challenge for the platform. An early implementation of the Metaverse presents a limited number of successful participants. When more participants access workplaces, the consequent uploading and downloading requests rise consistently. The Metaverse platform may suffer from processing delay or bottleneck problems in this case. Hence, the required bandwidth must be exceptional to ensure the scalability of Metaverse through sophisticated networking techniques that Blockchain can grant.

C. EDGE RESOURCES SHARING

In the Metaverse network, participants may interact with the virtual world using VR and AR technologies. To access the providers of Metaverse services currently, participants use Metaverse local devices such as head-mounted glasses. Nevertheless, using Metaverse local devices for computing faces two main challenges: firstly, the limitations of these devices' computing and communication resources. Second, the dynamic and constant movement of devices with the distribution of the local computing devices. Blockchain can fill this gap and optimize resource sharing in Metaverse securely and with transparency to help Metaverse users finish more offloading tasks in time.

D. INTEROPERABILITY AND INCENTIVE COMPATIBILITY

The interoperability within numerous Metaverse applications, particularly when participants shift from one platform to another, should be seamless to facilitate the partici-

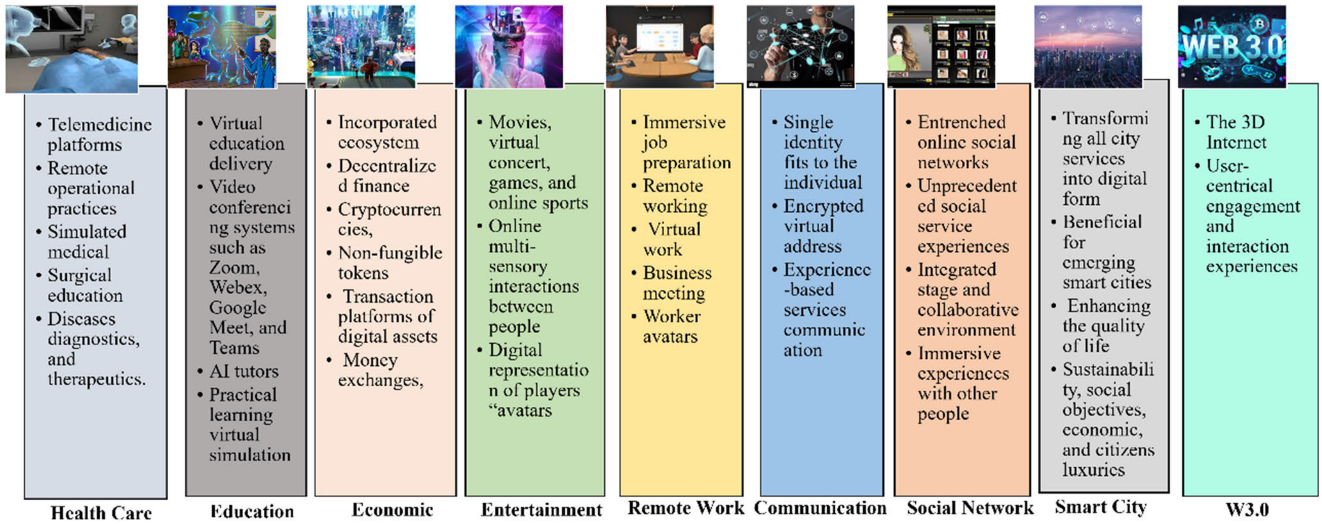

FIGURE 12. Metaverse as a services provider.

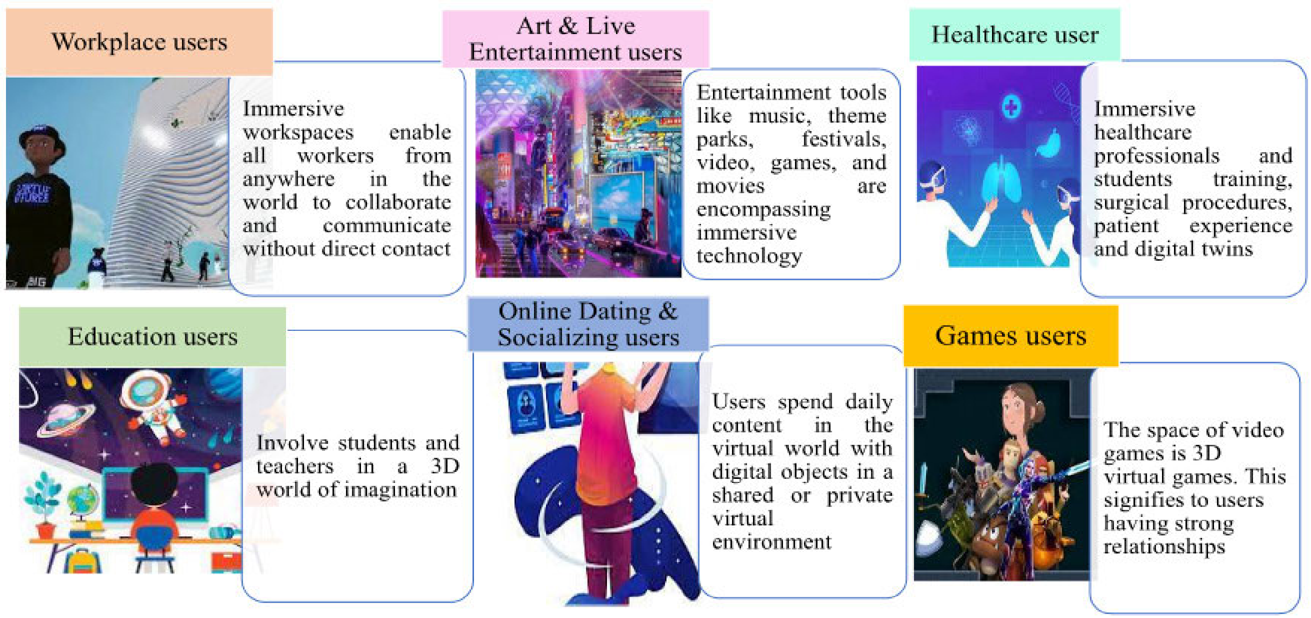

FIGURE 13. Diverse users in the metaverse system.

FIGURE 14. Data within the metaverse.

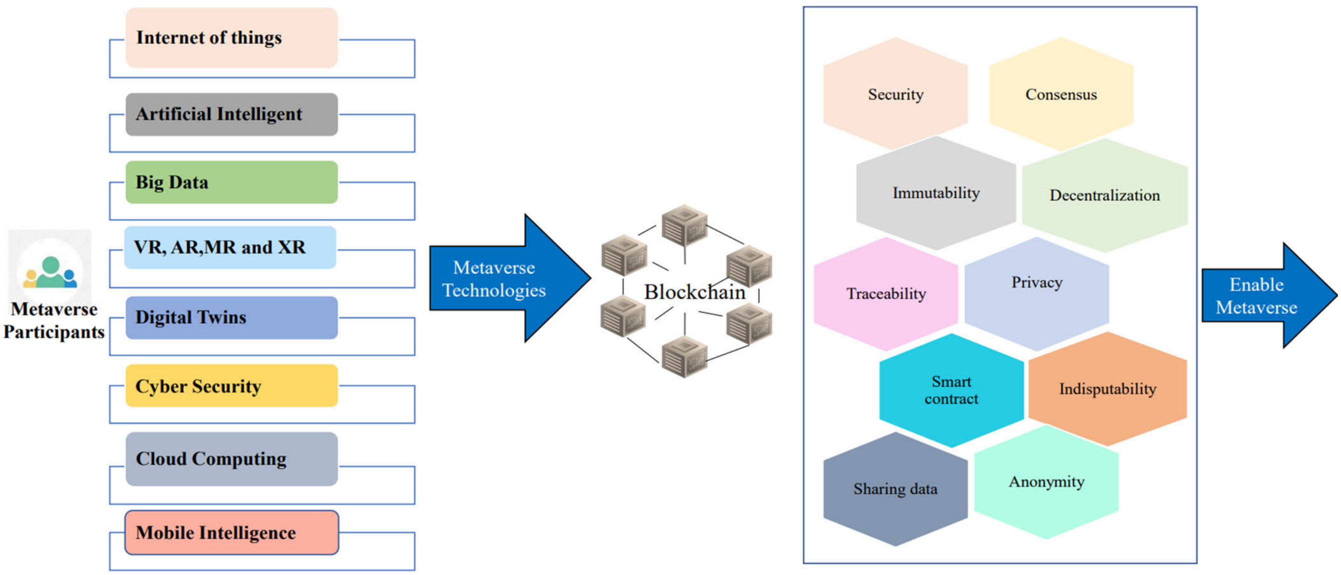

FIGURE 15. Blockchain's impact on metaverse technologies.

pants' engagement and enrich their experience. Besides, data interoperability across virtual / augmented reality is limited because of the different environments in which they are developed, which requires compatibility. When using blockchain, a cross-chain protocol, it is promising to transmit data between two or more blockchains housed in different virtual worlds. Because of the interoperability of the blockchain, users may transition between different virtual worlds more readily.

E. ACCESSIBILITY FOR DATA DEVICES AND NETWORKS

In contrast to the Internet, where access does not need specific devices, Metaverse operators are required to use specific devices such as a headset, contact lens, and glass for higher interactivity in the virtual world, leading to significant limitations in accessibility. In the future, the accessibility in Metaverse must evolve and be accomplished with unwearable and in-service devices. Furthermore, interaction techniques must be developed where users can feel, smell, and taste in the virtual world rather than only hear or see. Network accessibility is an additional potential barrier in the Metaverse network, as are the interfacing devices issues of the Metaverse. Sufficient bandwidth must grow with the increase of diverse participants' platforms, applications contents, and data.

F. SHARING DATA

Metaverse participants and applications collaborate and share data on the same platforms. The data gathered from diverse applications and different AR/VR and IoT devices in the Metaverse will be utilized to generate personalized systems tailored to participants' activities. Furthermore, Organizations can perform data analytics across the Metaverse by distributing information across applications. Shared data will help recognize customers' behavior, assess advertising, customize the content, establish creative strategies, and build products in the Metaverse. Alternative prospects in sharing data in the Metaverse include several applications like healthcare, traffic optimization, mass media, and games, which will produce a real-time environment with a large volume of data, requiring more flexible data sharing and manipulation. Regarding this issue, blockchain techniques can play valuable roles in data sharing within the Metaverse:

1. In all applications, transactions are transparent and accurate. The transaction records are immutable and decentralized and can only be seen by the participants.
2. The block owner will have comprehensive control over the block information.
3. Data inspections and validation are easy and with low cost and time when using the blockchain Hyperledger.
4. Blockchain heterogeneous smart contracts can generate flexible data sharing when all participants autonomously agree and execute a particular transaction without the need for a third party, hence reducing the transaction cost.

G. DATA STORAGE

Every participant login within the Metaverse automatically creates a data file, which continuously enlarges and contains more and more data due to social interactions between Metaverse applications. Massive storage is required as huge amounts of data generated by members in real-time require data processing and retrieving. Hence, Metaverse developers must consider data storage to be a high priority. Metaverse's physical central digital data storage faces many challenges: limitations of capacity, corruption, risk of loss, and damage, as revealed especially in health care, gaming, IoT, etc. When Metaverse transactions are completed through a decentral-

TABLE 4. Case studies of metaverse applications aligned with blockchain roles and platform pillars.

Metaverse applications	Case Studies	Required Pillars of metaverse Platforms					Roles of Blockchain-based
		Human-Centered Communication	Ubiquitous connections	Immersive Virtual scenes	Open time and Space Merging	User Fulfilments	
Healthcare	• Tele-health 2.0 • Virtual Surgical Simulation • Immersive medical Education • Virtual hospital • Immersive VR therapy	Crucial	High	High	Limited	Limited	• Securing shared healthcare data, • Privacy and ethics • Securing the healthcare ecosystem • Data Accessibility • Data Security and sharing. • Scalability
Education	• Self-learning experiences • AR in virtual content • VR in practical exercises • Interactive E-learning • Mirror world(Virtual conferences)	Crucial	High	High	High	Limited	• Secure Education Environments • Data Security and privacy • Securing education ecosystem • Data Accessibility • Intellectual Properties • Scalability
Ecosystem	• Integrated platform for complementors, consumers, platform owners, and orchestrators • AR/Vr/ and ER for Goods production • Banking • Retail Industry and Digital marketing • Brands Business (Nike, Starbucks)	Crucial	High	High	Medium	Limited	• Secure Transactions • Using smart Contract • Intellectual Properties • safeguards Data Security, sharing and privacy.
Entertainment	• The entertainment industry (Concerts, Gaming, Holograms) • VR theme parks • Competitive entertainment (Sports betting) • VR/ER/AR in Museum content and Tourism	Crucial	Medium	High	High	High	• User identity • Data Security and privacy • Intellectual Properties • Data Accessibility
Remote work	• Remote office work(teamwork collaboration) • VR/AR and DW for remote meeting • Marketing and Virtual Customer services	Crucial	High	Medium	High	Limited	• Data Security and privacy • Data Accessibility • Authorization • Multi-layer authentication • Scalability • Edges resource sharing.
Communication	• Holographic-Type Communication (HTC) • Multisensory media • Mobile AR • Mining operations	Crucial	High	Medium	High	Limited	• Secure Identity information • Multi-layer authentication • Scalability Edges resource sharing &management

TABLE 4. *(Continued.)* **Case studies of metaverse applications aligned with blockchain roles and platform pillars.**

Social Network	• Interpersonal communication platforms using VR, AR, ER: • Microsoft Mesh • Jelly application, • the Honnerves Rainbow Universe, • Little Iceland by Xiaoice	Crucial	High	Medium	High	High	• Data Security and privacy • Authorization • Multi-layer authentication • Data Accessibility • Scalability
Snart City	• Transportation and automotive industry • Energy industry and smart grid • Supply chain management and logistics • Smart Home	Crucial	High	High	High	Limited	• Secure user identity and Transactions • Data Accessibility • Using smart Contract • Data Security, sharing and privacy. • Scalability • Edges resource sharing &management
Web 3.0	• Business implication web applications i.e. customer engagement • Centralized Identity Providers i.e. digital identities and contents.	Crucial	High	Medium	High	Limited	• Data Security, sharing and Privacy. • Data Accessibility • Authorization • Multi-layer authentication • Scalability • Edges resource sharing &management

ized blockchain, the time it takes to detect and tag data will be lower. Meanwhile, blockchain serves as a cooperative platform for data researchers. In addition, data backup, trustworthiness, transparency, and availability are guaranteed when blockchain is applied.

H. LATENCY AND ENERGY EFFICIENCY

In blockchain, cross-chain protocol expansion permits data interchange, improving Metaverse interoperability between spectrum resources of edge networks and wireless devices. Unfortunately, the energy resources of these devices are restricted and prone to challenging resource allocation problems for VR and AR streaming services. Considering the energy expenditure of blockchain is also vital for the Metaverse, specifically for the telecommunication ecosystem, since 5G systems are tailored towards ultimate energy efficiency. Blockchain developers are undertaking immense changes in the direction of a significantly more efficient technology solution, mainly in the mining and validation methodology, which consumes energy. Also, a shift from simple averaging to fine-grained analysis is required to address distribution and quality of service (QoS) issues among heterogeneous users in the performance analysis and optimization of all Metaverse technologies, including AI, IoT, digital twins, and extended reality, which are energy harvesters.

VIII. FUTURE RESEARCH DIRECTION

Future research can investigate deeper into scalability solutions for blockchain-based Metaverse platforms. This includes exploring innovative consensus mechanisms and layer-2 solutions to ensure the efficient processing of a growing number of transactions and assets.

Interoperability challenges in the Metaverse can be overcome by developing standardized protocols that allow seamless asset transfer and communication between different virtual worlds or platforms.

More extensive studies focused on edge computing and resource-sharing techniques need to be conducted in order to significantly increase the efficiency of Metaverse applications and reduce user latency. Conventionally centralized cloud infrastructures are facing issues from the increasing need for these immersive virtual environments. Edge computing is a significant way to address this problem since it allows for more effective processing power deployment in the Metaverse by putting it near end users and applications. Edge computing in the Metaverse reduces latency and data transit times by locating processing resources adjacent to users, making the user experience responsive and seamless.

More advancements in AI, VR, and AR technologies promise to enhance user experiences and virtual environments. These technologies will integrate AI algorithms with VR and AR systems, creating more immersive and adaptive environments. AI-driven predictive systems and machine learning could enhance VR and AR content creation. Future research can focus on reducing computational requirements and developing AI models for high-fidelity VR and AR experiences. These technologies could be applied in various domains, including education, entertainment, healthcare, and training simulations.

Interdisciplinary collaboration between blockchain, VR, and AI experts is crucial for creating a unified Metaverse. This approach involves pooling knowledge from various fields and establishing shared standards, protocols, and frameworks for seamless interoperability. This approach can drive advancements in AI algorithms, blockchain-based security, and immersive virtual experiences. It also involves developing ethical and regulatory frameworks to ensure user safety and privacy in the Metaverse.

For blockchain networks to be more sustainable in Metaverse applications, research must address the significant energy consumption and environmental effects of these networks. The main goal is to figure out how to lessen the carbon footprint that comes with blockchain technology. The goal is to increase the energy efficiency of blockchain networks by using novel algorithms, protocols, and hardware optimizations. Developing environmentally friendly and scalable solutions for blockchain integration within the Metaverse entails investigating consensus processes, data storage techniques, and computation algorithms. These initiatives aim to minimize the environmental impact of blockchain technology while supporting the long-term survival of Metaverse networks.

The investigation of how blockchain-based Metaverse platforms might transcend digital realms and transform a range of industries is explored through the integration of these platforms with real-world applications. The goal of research is to determine how blockchain technology in the Metaverse may be applied in real-world contexts to industries including entertainment, healthcare, and education. This entails creating protocols and systems that allow for safe and decentralised data management, authentication, and transaction procedures. The objective is to develop interoperable systems that take advantage of the immutability and transparency of blockchain technology to enhance security, privacy, and trust in practical applications. Blockchain, for example, can be used to safeguard patient data in healthcare and validate credentials in education. It can verify the digital ownership of assets in the entertainment industry. The study investigates these uses to highlight the possibilities of a numerous blockchain-based Metaverse platforms to revolutionize of industries, fostering an environment of innovation, transparency, and trust.

IX. CONCLUSION

Blockchain technology promises to reshape the development and administration of virtual realms within the Metaverse. Its role in creating a secure, decentralized infrastructure is pivotal in fostering transparency and facilitating the seamless transfer of virtual assets and transactions among users. In doing so, it addresses various challenges associated with managing the Metaverse, including digital asset tracking, privacy safeguarding, and security reinforcement. As the blockchain-based Metaverse continues to evolve, there is a growing need for research and innovation to address critical concerns such as scalability, interoperability, and the efficient allocation of edge resources.

Given the ongoing communication, computational needs, and security challenges of metaverse development, we have reviewed the latest advancements in blockchain and intelligent networking. The Metaverse must have a reliable and trustworthy network to seamlessly bridge the virtual and physical worlds. Hence, our investigation explores the advantages of merging blockchain and intelligent networking within the Metaverse. The goal is to unify the physical and virtual domains, establishing a more reliable, secure, and effective environment to deliver users an immersive experience. Finally, we presented the research gaps preventing blockchain from becoming a significant innovation in the Metaverse. The current focus in research circles involves advancing blockchain technology and its application in the Metaverse to elevate overall living standards. Despite the ongoing efforts to employ blockchain in sustainable Metaverse initiatives, numerous challenges and limitations persist, demanding further investigation and resolution.

COMPETING INTERESTS

The authors declare no competing interests within the last three years that could be perceived as influencing the work submitted to *Applied Intelligence* journal.

AUTHOR CONTRIBUTIONS

Conceptualization: Muna Elsadig and Ashraf Osman Ibrahim; Methodology: Muna Elsadig and Ashraf Osman Ibrahim; Investigation: Manal Abdullah Alohali and Anas Waleed Abulfaraj; Resources: Muna Elsadig, Manal Abdullah Alohali, Ashraf Osman Ibrahim, and Anas Waleed Abulfaraj; Writing—Original Draft Preparation: Muna Elsadig and Ashraf Osman Ibrahim; Writing—Review and Editing: Ashraf Osman Ibrahim and Anas Waleed Abulfaraj; Visualization: Muna Elsadig and Ashraf Osman Ibrahim; All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The authors confirm that they have no financial or non-financial affiliations or involvement with any organization or entity that could potentially influence the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY AND ACCESS

Not applicable

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MUNA ELSADIG (Member, IEEE) received the Ph.D. degree in information technology and network security from University Technology PETRONAS (UTP), Malaysia. She is an Assistant Professor with the Department of Information System, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University (PNU), Saudi Arabia. Her research interests include blockchain technology, cyber security, healthcare quality, intelligent security systems in IoT, and cloud and risk assessment. She is a reviewer of many international journals and conferences.

MANAL ABDULLAH ALOHALI received the Ph.D. degree from the University of Plymouth, U.K. She is an Assistant Professor of cyber security with the Information Systems Department, Princess Nourah bint Abdulrahman University (PNU). Her main research interests include information security risk assessment, security behavior, awareness, and usability. She received a Research Excellence Award from PNU.

ASHRAF OSMAN IBRAHIM (Senior Member, IEEE) received the B.Sc. degree in computer science from Al-Neelain University, the M.Sc. degree in computer science from the University of Khartoum, and the Ph.D. degree in computer science from Universiti Teknologi Malaysia (UTM). Currently, he is a member of the Advanced Machine Intelligence Research Group, Universiti Malaysia Sabah. He has extensive experience in supervising and co-supervising postgraduate students, with over 20 postgraduate scholars successfully graduating under his guidance. In addition, he is an external and internal examiner/an evaluator of Ph.D. and master's theses at numerous universities. His research interests include applications of intelligence systems, machine learning, artificial neural networks, deep learning in cyber security and different areas, evolutionary computation, data science, big data analytics in different applications, and multi-objective optimization. He is currently serving as a journal Reviewer for many reputation journals, such as IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS, IEEE ACCESS, *Expert Systems with Applications*, *Engineering Applications of Artificial Intelligence*, *Biomedical Signal Processing and Control*, and *Journal of King Saud University Computer and Information Sciences*.

ANAS WALEED ABULFARAJ received the B.S. degree in information systems from King Abdulaziz University, Jeddah, Saudi Arabia, in 2012, and the M.S. and Ph.D. degrees in human–computer interaction from DePaul University, Chicago, USA, in 2016 and 2021, respectively.

Currently, he is an Assistant Professor with the Department of Information Systems, Faculty of Computing and Information Technology, King Abdulaziz University, Rabigh, Saudi Arabia. His research interests include human–computer interaction, machine learning, artificial intelligence, and cybersecurity.