IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 25 May 2023, accepted 12 June 2023, date of publication 15 June 2023, date of current version 13 July 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3286696

TOPICAL REVIEW

Exploring the Potential of Metaverse Technology in Healthcare: Applications, Challenges, and Future Directions

HIDAYAT ULLAH[1], SELVAKUMAR MANICKAM[2], MUATH OBAIDAT[3], (Senior Member, IEEE), SHAMS UL ARFEEN LAGHARI[2], AND MUEEN UDDIN[4], (Senior Member, IEEE)

[1]College of Management, Shenzhen University, Shenzhen 518055, China
[2]National Advanced IPv6 Centre (NAv6), Universiti Sains Malaysia, Gelugor, Penang 11800, Malaysia
[3]Department of Computer Science, The City University of New York, New York, NY 10017, USA
[4]College of Computing and Information Technology, University of Doha for Science and Technology, Doha, Qatar

Corresponding authors: Mueen Uddin (mueen.uddin@udst.edu.qa) and Selvakumar Manickam (selva@usm.my)

This work was supported by the Qatar National Library (QNL).

ABSTRACT In recent times, the emergence of the Metaverse has garnered worldwide attention as an innovative digital space that holds immense potential to provide a wide range of health services to medical professionals and patients. With increasing stress on healthcare systems, it has become crucial to explore the latest and cost-effective solutions that can provide fast and reliable medical services. The focus of this study, therefore, is to explore applications of metaverse in various health care systems and elaborate on how it can efficiently improve the clinical management of patients. Consequently, an in-depth assessment of the metaverse has been carried out, while covering its core fundamentals, key technologies, and diverse applications in healthcare and medicine, including but not limited to, emergency response learning, hands-on experience in anatomy learning, orthopaedics, paediatrics and so on. To carry out the study, we have used an exploratory approach to analyze qualitative data on healthcare metaverse services in our systematic review. Relevant articles from scientific databases such as Web of Science, Springer, Scopus, and IEEE have been identified, and the analysis has been conducted using the PRISMA reporting guideline to ensure transparent and comprehensive reporting. The results of the study suggest that the metaverse has the potential to transform healthcare systems by introducing novel methods for delivering healthcare services. Metaverse's AR/VR technologies can enable remote medical consultations and training, benefiting patients and healthcare professionals. Additionally, patients can access health-related information and resources, empowering them to manage their health better and make more informed decisions.

INDEX TERMS Metaverse, surgical simulators, computer-assisted treatments, pre-operative counseling, augmented reality, artificial intelligence, robotic surgery, orthopedics.

I. INTRODUCTION

Healthcare services have stood out as a cornerstone factor in upholding the global populace's comprehensive psychological, physical, and social well-being [1]. The essential nature of healthcare services is underscored by their ability to mitigate the harmful impacts of disease, injury, and illness while simultaneously promoting wellness and longevity. However, despite the protracted developmental journey of the healthcare industry, it has witnessed a swift and dynamic metamorphosis, predominantly catalyzed by its integration with cutting-edge technological advancements [2] – and the Metaverse is one such cutting-edge technological advancement that holds the promise of better future for the healthcare industry. Presently, this sector faces many issues and challenges, such as the widespread prevalence of chronic diseases, shortage of advanced equipment in community hospitals, inadequate knowledge of high-end technologies,

The associate editor coordinating the review of this manuscript and approving it for publication was Dominik Strzalka.

and low patient awareness of different medical procedures, to name a few [3]. These major impediments have made it imperative to bring healthcare services to the doorstep of individuals [4], [5]. The COVID-19 pandemic further exacerbated the situation and has been the primary impetus behind accelerating quick change across the healthcare ecosystem. It has forced all stakeholders to reevaluate their approach to this industry and has necessitated the unavoidable adoption of advanced technologies to cope with the changing landscape [6]. In this scenario, the Metaverse could prove a game changer. It represents a culmination of diverse state-of-the-art technologies such as Augmented Reality, Virtual Reality, Artificial Intelligence, Blockchain, Quantum Computing, Robotics, and the Internet of Medical Devices (IoMT), among many others. By harnessing the potential of these advanced technologies, it offers exciting opportunities for exploring innovative solutions to deliver superior-quality healthcare treatments and services. With its potential to provide life-like experiences to patients and healthcare providers, the Metaverse presents new opportunities for improving healthcare outcomes.

Contemporary literature suggests an increasing interest in the metaverse and healthcare domain. However, despite numerous studies on the implementation of metaverse technologies in healthcare, they have limitations and fail to address certain areas. For instance, [7] only explores potential applications of metaverse technologies in healthcare without delving deeper into the specifics of each domain. while [8] focuses on the significance of Augmented Reality/Virtual Reality AR/VR technology in the healthcare sector but does not provide enough information on how to utilize it effectively. Reference [9] scrutinizes the influence of metaverse in cardiovascular medicine but lacks analysis of its potential impact on other medical specialities. Reference [10] advocates for the fusion of AI and blockchain in the metaverse for superior healthcare services, but the study lacks a practical demonstration of such a system. Reference [11] identifies the areas in which metaverse technology could be used in healthcare, but the study only reviews nine studies from South Korea and is limited in its scope. Therefore, a comprehensive study is needed to examine the potential of metaverse technologies in healthcare, identify areas that require further research, and provide actionable insights for healthcare practitioners and companies interested in implementing such technologies.

It can be concluded that the ongoing digital revolution in the healthcare industry has gained significant momentum due to the COVID-19 pandemic. While this shift towards telemedicine and telehealth has been vital in providing healthcare services during the pandemic, it has also exposed limitations, challenges, and equity concerns in the digital healthcare infrastructure. Therefore, there is an urgent need for research on metaverse technology for healthcare systems to address these issues, adapt to pandemic-induced changes, and meet the evolving requirements and goals of health-care consumers. The proposed research will systematically investigate how metaverse technology can optimize patient satisfaction, improve medication adherence, and enhance the patient-clinician experience by leveraging advanced digital tools and services. Furthermore, this study will strengthen the healthcare industry's ongoing strategies to meet necessary market and technology requirements while positioning it to respond to new business opportunity development in metaverse services. Given the pressing need for digital healthcare infrastructure that can meet the demands of modern healthcare, it is crucial to explore the potential of metaverse technology in transforming and improving virtual healthcare services.

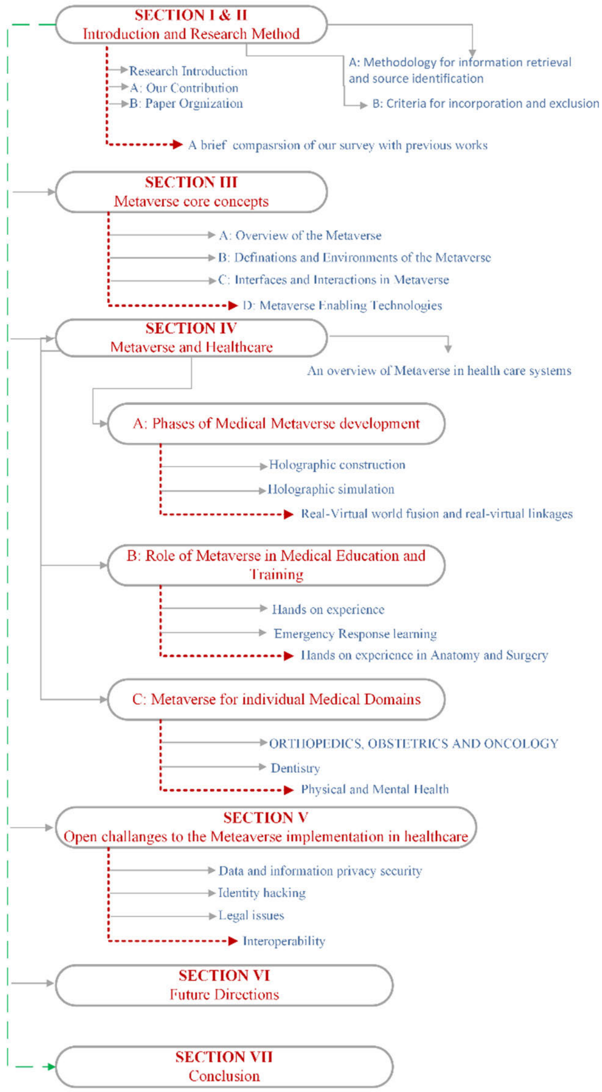

FIGURE 1. Paper organization.

A. OUR CONTRIBUTION

Metaverse harbors the potential to tackle the predicaments of numerous domains by revolutionizing communication modalities among users and devices by incorporating modern technological frameworks. However, the present manuscript focuses upon a thorough and all-encompassing survey of the Metaverse's significance in addressing the prevailing afflictions of the healthcare domain. It meticulously considers the characteristics, current implementations, and impediments surrounding the Metaverse and its capacity to fully leverage its capabilities toward healthcare. In essence, this study's contributions can be briefly summarized as follows: This article presents a holistic perspective of the advantages of the Metaverse in the healthcare systems, highlighting the underlying inspiration for adopting this technology and identifying its key enabling technologies.

- By conducting an all-encompassing analysis of Metaverse implementations in various healthcare domains, including medical education and training, clinical and mental healthcare, and physical fitness, etc., this empirical investigation underscores the immense value that Metaverse technology can proffer to the healthcare system.
- Through the presentation of ongoing projects and practical examples of Metaverse in the healthcare systems, readers could gain an insight into the practical applications of this technology in addressing issues within the healthcare industry.
- Finally, the manuscript delves into a comprehensive analysis of the potential challenges and obstacles in integrating Metaverse technology in the healthcare sector.

Table 1 presents studies that indicate the Metaverse's potential uses in healthcare, such as clinical care, physical well-being, mental wellness, and education. Additionally, Augmented Reality/Virtual Reality (AR/VR) technology has a significant impact on the healthcare sector and can be applied in several ways. By integrating artificial intelligence and blockchain technologies into the Metaverse, it is possible to provide secure and efficient healthcare services. Medical imaging is the most practical application of the Metaverse for educational, interventional, and communication services in healthcare. However, the intersection of the Metaverse and health promotion necessitates additional research and investment to develop feasible and valid programs.

B. ORGANIZATION OF THE DOCUMENT

The paper's initial section lays a robust foundation for the topic at hand, delivering a comprehensive introduction. Section II is dedicated to outlining the research methodology employed. Section III delves into the fundamental concepts and key technologies underlying the Metaverse, setting the stage for the subsequent exploration of adopting the Metaverse in healthcare in Section IV. Within this section, there are three subsections: phases of medical Metaverse development, the role of the Metaverse in medical education and training, and the Metaverse's application in individual medical domains. These subsections provide detailed use cases that demonstrate the potential of integrating the Metaverse into the healthcare industry. The study concludes with Section VII, which discusses the challenges and presents promising areas for future research on leveraging Metaverse-based solutions in the healthcare sector. The organization and layout of the paper are visualized in Fig. 1.

TABLE 1. A brief comparison of our survey with previous works.

Ref &Year	Contribution
[2] 2023	This scholarly article presents a comprehensive review of the Metaverse's potential applications in healthcare, including enabling technologies and ongoing projects, as well as identifying challenges and proposing potential solutions for future research.
[7] 2021	Expounds upon the implementation of metaverse technologies in a multitude of healthcare domains including clinical care, physical well-being, mental wellness, and education.
[8] 2012	This inquiry delves into the study of collaboration in virtual worlds and healthcare simulations. Explores the significance of Augmented Reality/Virtual Reality (AR/VR) technology in the healthcare sector, analysing its potential impact and applications in the field.
[9] 2022	Scrutinizes the influence of the metaverse in the realm of Cardiovascular medicine, comprehensively dissecting its function and capacity within the field.
[10] 2023	The manuscript advocates for the fusion of artificial intelligence and blockchain technologies within the metaverse, intending to offer superior, expeditious, and highly secure healthcare services in the virtual realm, while simultaneously promoting a verisimilar user experience.
[11] 2022	The authors conducted a scoping review to identify the areas in which this emerging technology could be used in healthcare. The review included nine studies, most of which were published in 2021 and originated in South Korea. The studies showed that the Metaverse can be used for educational, interventional, and communication services in healthcare, with medical imaging being the most practical application.
[12] 2022	The survey covers many supplementary domains, including telemedicine, clinical care, and veterinary medicine, among others.
[13] 2022	By thoroughly r**eviewing** existing literature, this study aims to examine the use of metaverse services as a business model in the healthcare sector, analyzing current qualitative data and trends in the industry to suggest potential strategies.
[14] 2022	The study aims to explore the intersection of the metaverse and health promotion. The review of existing literature covers prevention and treatment, education and training, and research. The study found a dearth of articles on the subject, with most being reviews or editorials. While the study suggests that the metaverse could be useful for health promotion, developing feasible and valid programs requires further research and investment.
2023 Ours	This article explores the potential of Metaverse in healthcare. It reviews applications in clinical care, medicine, education, and fitness. Ongoing and upcoming projects are presented as examples. Potential challenges and research challenges are identified to facilitate the adoption of Metaverse technology in healthcare.

II. RESEARCH METHOD

A. METHODOLOGY FOR INFORMATION RETRIEVAL AND SOURCE IDENTIFICATION

The present investigation advocated in Fig. 2. implemented the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to discern pertinent research articles for incorporation into the study. The PRISMA methodology is a recognized and widely used framework for conducting systematic reviews that aim to provide a comprehensive and transparent approach to the literature review process. It enables researchers to consistently and reliably identify, evaluate, and synthesize pertinent studies [15]. By adhering to the PRISMA guidelines, researchers can ensure the quality and rigor of their review, minimizing the chances of bias and increasing the overall trustworthiness of their conclusions.

The study aimed to undertake a thorough search by utilizing a diverse range of scientific databases, including Web of Science, Springer, Scopus, ACM, and IEEE. To ensure the investigation was comprehensive, pertinent topic-related keywords such as ''Metaverse'' and ''medicine'' or ''health'' or ''immersive'' were used without temporal limitations spanning from 2017 to 2023. The study was structured and executed following scoping and systematic review guidelines, with adherence to the Population, Context, and Concept (PCC) framework [16]. Therefore, the investigation was formulated by incorporating the distinctive elements of the PCC framework, to ensure a comprehensive and exhaustive analysis of the existing literature.

B. CRITERIA FOR INCORPORATION AND EXCLUSION

In this systematic survey, we employed a rigorous search strategy by using a range of reputable digital libraries, including ACM, IEEE, MDPI, Science Direct, and Springer, spanning from 2017 to 2023. We narrowed our search to focus on keywords such as ''Metaverse'' and ''health'' or ''medicine'' or ''medical'' and retrieved a substantial number of articles across the databases. The identification process returned a total of 2183 results. All the titles for the screening process (as established by the PRISMA checklist) were imported to EndNote 20 as a single library to remove the duplicates via title, author, journal, and year. The resulting articles amounting to 417 were exported as a single excel file for the title and abstract screening which resulted in the exclusion of 31 articles as they didn't fit the criteria. Finally, 386 full-text articles were accessed for eligibility of which 300 were excluded for various reasons including irrelevancy, duplication, and not-availability of the full text. The final basket for the quality synthesis contained 96 articles along with 13 articles included via manual search.

Journal-wise statistics are produced as: ACM returned 391 articles, out of which we found 24 relevant articles, and after careful examination, we ultimately selected 10 articles. Similarly, we found 54 relevant articles among the 395 retrieved by IEEE, and we selected 30 articles after thorough scrutiny. We also retrieved 556 articles from Science Direct, and after a detailed evaluation, we selected 31 articles. Additionally, we retrieved 148 articles from MDPI, out of which we selected 20 articles, and from Springer, we retrieved 407 articles, among which we selected 5 articles for this study. Fig. 2. provides a clear overview of our methodology.

In addition to our systematic review, we also conducted a comprehensive analysis of the existing literature to identify the relevant studies that have been conducted on not only specific healthcare domains, such as cardiovascular health, mental health, rehabilitation, and others but also on several other domains [17], [18], [19], [20], [21]

This related work section will provide an overview of the studies identified in the search process. By synthesizing the results of our systematic survey and the related work section, we aim to offer a complete evaluation of the application of Metaverse in healthcare, including the benefits and challenges associated with its implementation.

While searching for relevant research publications, several factors were considered when deciding which studies to exclude and which to include. This included duplication, language (with only English-language papers being considered), and relevance to the subject matter. Articles that we deemed to be unrelated to Metaverse and Healthcare and those that contained previously published information on the same topic were also eliminated from consideration. Additionally, resources such as case series and reports, brief communications, and editorial comments were not included in the final selection of papers.

III. METAVERSE CORE CONCEPTS

To comprehend the soundness and practicability of utilizing the metaverse in medicine, gaining an in-depth understanding of its fundamental concept is imperative. The following section will delve into the foundational work that has been carried out on the metaverse, its enabling technologies, and what it holds for.

A. OVERVIEW OF METAVERSE

For nearly three decades since the inception of the internet, the idea of the metaverse has existed. However, only recently has the metaverse witnessed substantial growth, attributable to the remarkable advancements in 3D gaming technology. The portmanteau term ''metaverse'' stems from the Greek prefix ''meta,'' signifying ''beyond'' or ''transcendent,'' and the suffix ''verse,'' implying ''a universe or realm.'' The idea was first introduced by Neal Stephenson in ''Snow Crash,'' one of his science fiction novels from 1992 [22]. As of late, the term ''metaverse'' has proliferated as a prominent buzzword in the technological sector. This trend has been further amplified by the October 2021 proclamation of Facebook's CEO, Mark Zuckerberg, wherein the organization declared its rebranding as ''Meta'' with a commitment to prioritize the advancement of the metaverse.

B. GROWTH OF METAVERSE

Considering its vast potential and the exponential growth witnessed by the metaverse, it would not be an overstatement to regard it as the future's major digital innovation and a natural successor to contemporary internet technology [23]. A plethora of significant technology conglomerates, such as Facebook, Tencent, Bytedance, Microsoft, NVIDIA, and

Unity, have already declared their foray into the metaverse, showcasing their vested interest in this revolutionary domain that promises to reshape the digital landscape [24].

According to industry projections, the metaverse sector is expected to witness a significant upsurge, with its value predicted to surge from USD 500 million in 2020 to a staggering USD 800 billion by 2024. The prediction is that the surge of the augmented reality market will surpass the virtual reality market size by a great extent, skyrocketing to a mammoth $855.3 billion in 2027 [25].

Moreover, the growth of the metaverse in healthcare has transformed traditional healthcare practices. The reliance on physical interactions with patients for assessing well-being has been disrupted by the COVID-19 pandemic, prompting the adoption of telehealth as an alternative solution. Telehealth employs digital technologies, such as telephone calls, video conferences, email, and messaging, to provide remote healthcare services. Its prevalence has surged, with 95% of US healthcare facilities equipped for telehealth services in 2020, a significant increase from 43% [7], [26] before the pandemic. Telemedicine encompasses digital medicine, e-health, telehealth, and m-health, representing the convergence of technology and healthcare.

C. DEFINITIONS OF METAVERSE

Technically, the ***Metaverse*** is a virtual reality simulation that transcends traditional 2D interfaces, offering a fully immersive 3D world with realistic representations of real-life environments and experiences [27]. However, despite widespread discourse about the concept, a definitive and universally accepted explanation of the term "Metaverse" remains elusive. Numerous experts have expounded on this phrase differently, resulting in a need for more consensus. Particular academics have characterized the Metaverse as an immersive three-dimensional collective milieu where individuals can partake in diverse economic, social, and cultural undertakings and engage with one another through avatars [28], [29]. Still, some other perspective characterizes it as a "virtual world," replicating the physical and geographical characteristics of the real world, creating a digital network space where avatars embody users [30]. As depicted in fig. 3. the different parts that make up the metaverse are the environment, which is like the world you're in, the interface, which is how you interact with the world, the interaction itself, and the security to keep everything safe.

1) ENVIRONMENTS OF METAVERSE

The metaverse, a complex digital realm that offers diverse environments for users, can be categorized into three types: realistic, unrealistic, and fused. In a real metaverse, the physical and geographical features are represented by the designer's purpose and interpretation, and the avatars' movements are limited, akin to the real world. Despite its benefits of delivering experiences similar to reality, some drawbacks exist, such as limitations in atmospheric, olfactory, and tactile sensations [30].

On the other hand, the unrealistic metaverse, a digital realm that removes the constraints of realistic time and space, offers limitless possibilities for users to create and experience the unattainable. However, constructing an exquisite environment and a consistent worldview is challenging [31].

The fused environment combines realistic and unrealistic elements, offering augmented and virtual methods [32]. While the augmented way adds virtual features to the real world, the virtual method reconstructs a new world based on the laws of reality. Both approaches have advantages and disadvantages, requiring careful consideration for an optimal user experience.

2) METAVERSE INTERFACE

From the interface perspective, the metaverse can be implemented through 3D, immersive, and physical methods [33]. While the 3D design is not a prerequisite for metaverse environments, most are created in a 3D format, albeit with varying degrees of detail. The 3D approach confers the advantage of enhanced realism; however, it suffers from service continuity issues, such as hardware requirements and rendering discrepancies between 2D and 3D screens. Immersion, on the other hand, is crucial for cultivating user engagement and ensuring a seamless experience. This method typically involves physical tools like VR to subsume the user's visual senses and facilitate face-to-face communication between avatars. Excessive immersion can lead to adverse psychological outcomes, including detachment and addiction [34].

Moreover, physical elements, such as inertia, can also contribute to realism in metaverse environments. While current technology offers solutions such as VR suits and gloves to mimic tactile sensations, it remains challenging to convey physical emotions. Applying physical laws in expansive virtual spaces poses a significant software burden.

3) INTERACTIONS IN METAVERSE

In the metaverse, interactions are grouped into coordination, social networking, and persona dialogue. Redefining and proficiently utilizing social networking involvement within the metaverse is difficult. Nevertheless, the enthusiasm for generating value via collaborative efforts beyond the scope of singular virtual reality encounters is mounting. The simulation of natural conversation is emulated through persona dialogue which mirrors the distinctive traits of non-playable characters (NPCs) [35].

As the metaverse relies on users' interactions, numerous studies underline the importance of networks. Certain studies propose that the internet and social networking services (SNS) are evolving into a virtual realm.

These services are a suitable medium for expanding the metaverse and serve as a backbone that connects people's interactions. While most metaverses focus on online user relationships, it is paramount to consider privacy and offline metaverses. Collaboration and communication are fundamental principles in the metaverse, where user avatars can

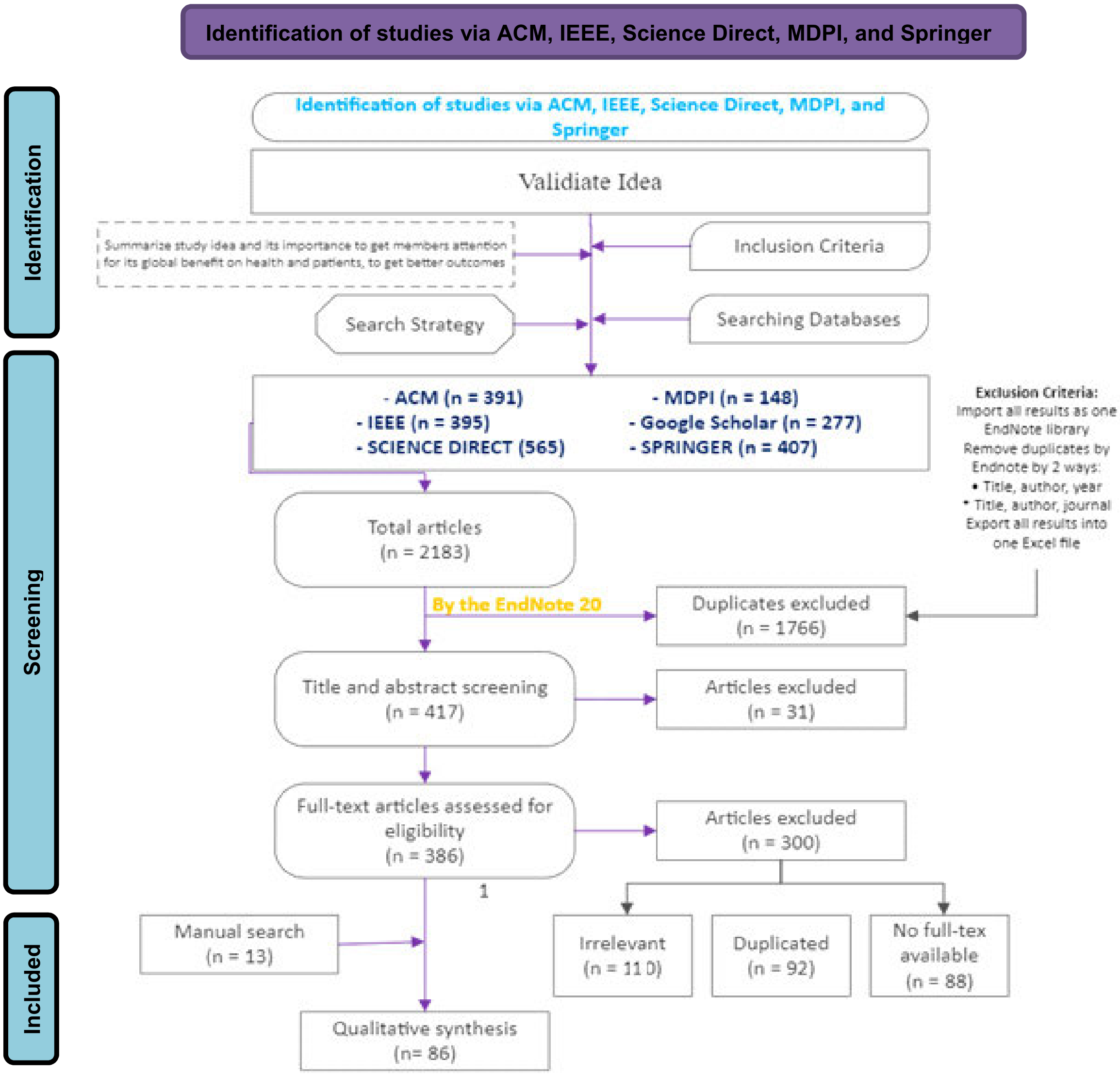

FIGURE 2. The PRISMA model guiding the article selection process.

work together and exchange experiences. This collaboration enables them to create new values and transcend time and space. However, because communication relies on sensor information, there is a chance of misunderstandings and erroneous judgments about hidden intentions. Conversations with Non-Player Characters (NPCs), including animals and objects, are possible in the metaverse [36]. These conversations enable users to convey and extend their experiences continuously.

D. METAVERSE ENABLING TECHNOLOGIES

At the core of the Metaverse's development lies six fundamental technologies, including but not limited to – artificial intelligence (AI), virtual reality (VR), augmented reality (AR), digital twinning, internetworking/telecommunication, and blockchain, visualized in the fig. 4. are the various Metaverse enabling subsystems that allow the Metaverse to function seamlessly. The said figure illustrates the key components that work in tandem to support the immersive and interconnected virtual world of the Metaverse. This visualization offers a comprehensive understanding of the underlying infrastructure required to facilitate the Metaverse's operations and highlights the interdependency between different subsystems.

1) EXTENDED REALITY (XR)

Technologies encompassing the integration of virtual reality (VR), augmented reality (AR), and mixed reality (MR), enable a fully immersive, multi-sensory experience, complete with real-time interaction between users, their avatars, and the virtual world. This unparalleled experience is made possible by technologies such as front-projected holographic displays, sophisticated human-computer interaction (HCI) techniques, including the innovative brain-computer interface (BCI), and large-scale 3D modeling [37]. However, although these technologies come under the umbrella term of XR, it is

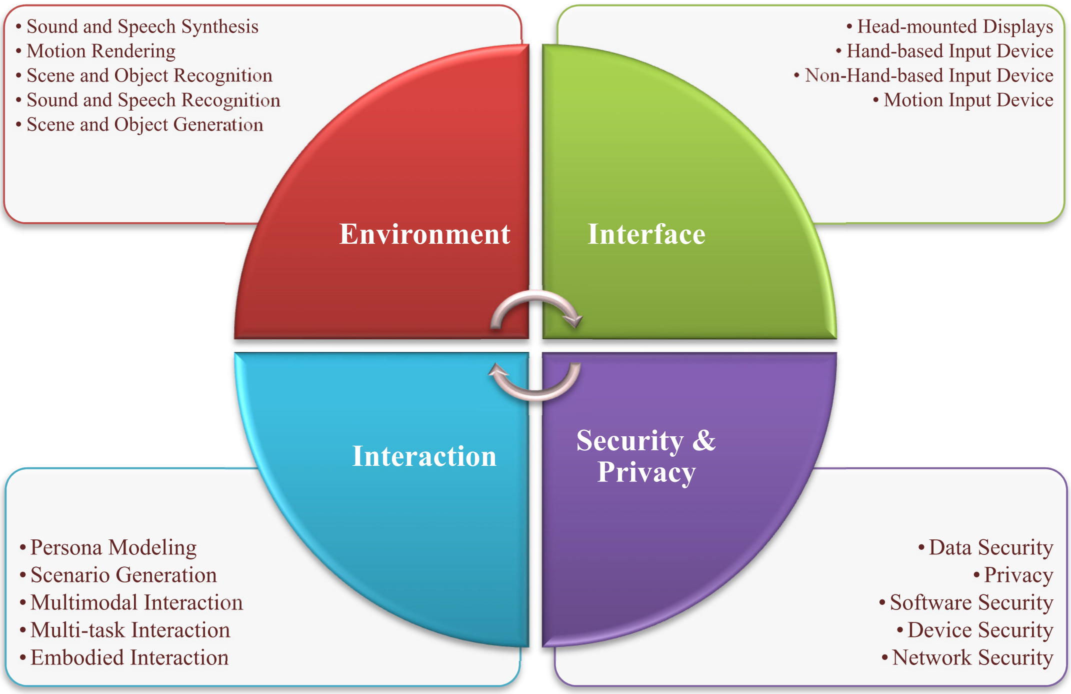

FIGURE 3. The Metaverse incorporates elements such as Privacy, security, interaction, and interface.

paramount to disambiguate these fundamental terms, as their meanings cannot be used interchangeably [38].

Augmented Reality (AR) is a state-of-the-art technology that can transform our perception and interaction with the surrounding environment. By seamlessly blending virtual objects into our physical environment, AR can enhance our sensory experience, enabling us to engage with digital information in real-time with remarkable precision. The success of AR depends on its ability to achieve seamless and accurate 3D registration of virtual and real objects, creating a harmonious fusion of the digital and physical worlds. Plane detection, object identification, face recognition, and movement monitoring are just a few advantages AR can offer [39].

Virtual Reality (VR) VR's hallmark is its unique capacity to engender a state of deep immersion [40], an experience that results from the intricate technical capabilities of its hardware and software to replicate reality convincingly within the user's sensory environment [41]. Contemporary VR based on head-mounted displays (HMDs) provides unparalleled levels of immersion and presence, allowing virtual environments to potentially influence users' cognitive, behavioral, and emotional states in previously impossible ways [42], [43]. The technology generates realistic images and sounds, creating a fully immersive experience that can be transformative [44].

Virtual reality can be utilized to educate students on clinical skills required in uncommon scenarios by offering simulated environments [45]. An instance of this would be using virtual reality in multiple casualty simulations to train students in the triage process for quick clinical assessment and proficiency acquisition, which can be as effective as practicing simulated care [46].

Fig. 5(a) showcases a variety of peripherals that can be utilized in conjunction with currently available HMDs. These peripherals include but are not limited to motion sensors, hand controllers, haptic feedback devices, and eye-tracking systems. It provides a visual representation of the different types of peripherals that can enhance the user's experience in virtual environments. Fig. 5(b) showcases some of the popular HMDs by different companies.

AR/VR technology can be leveraged in healthcare to offer tailored therapeutic interventions. For instance, a study [47] identifies four primary research domains in VR-aided therapy, which include post-traumatic stress disorder (PTSD), anxiety and fear-related disorders (A&F), diseases of the nervous system (DNS), and pain management.

Similarly, AR and MR technologies provide a way to enhance interaction between physical and virtual content, offering situated and authentic experiences, which are believed to be beneficial for healthcare education in various contexts [48].

Augmented Virtuality (AV) is a technology that provides a unique way to experience virtual environments. Unlike Augmented Reality (AR), which overlays virtual objects onto the real world, AV captures and integrates real-world objects into virtual environments in real-time. This creates a more immersive experience for users, who feel more fully embodied within the virtual space [49].

Mixed reality (MR) combines the features of both AR and VR, resulting in a unique perceptual environment

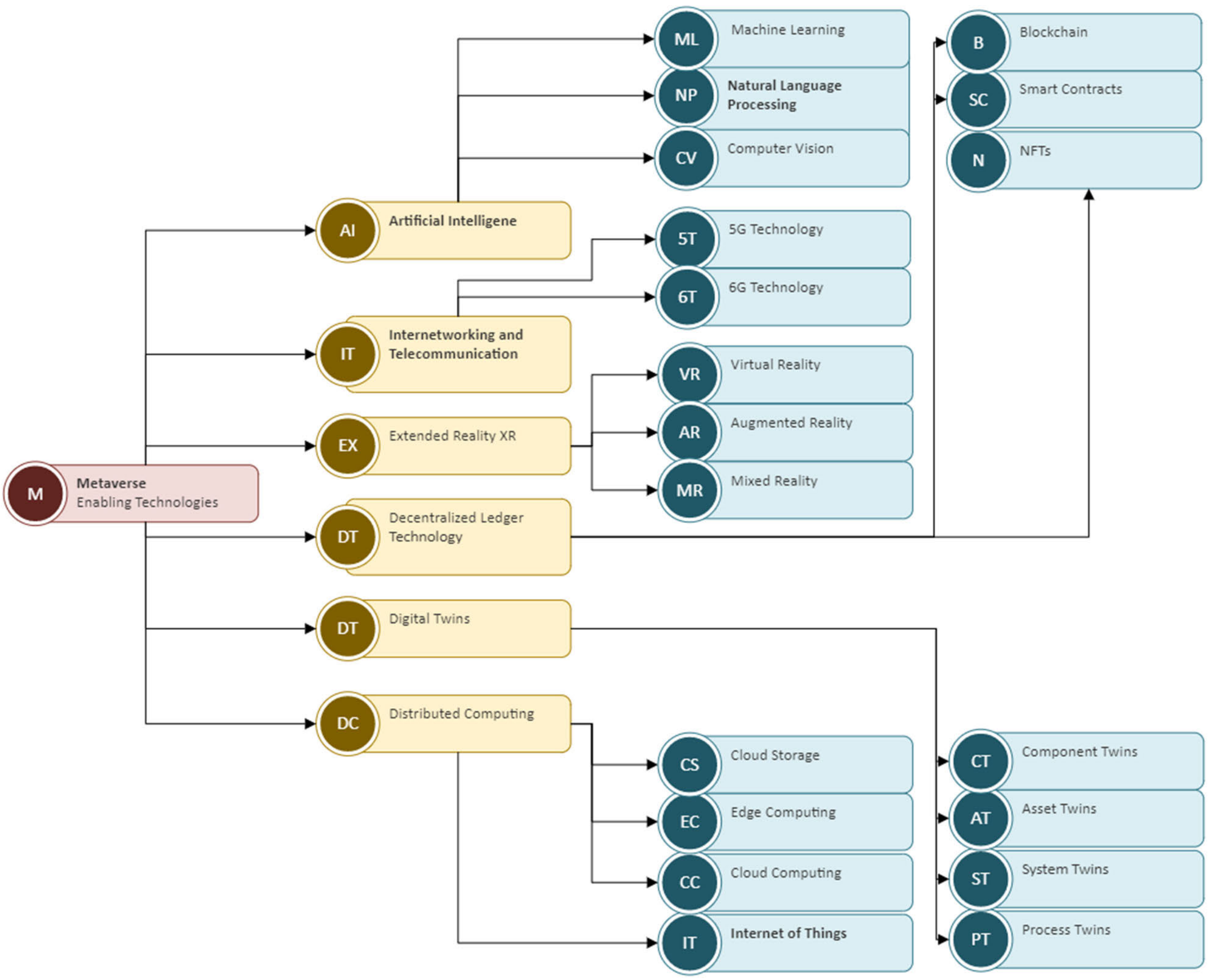

FIGURE 4. **Metaverse enabling technologies.**

where digital and physical entities can exist together and interact in real-time. A Mixed Reality (MR) environment blends real-world and virtual-world elements in a single display. Essentially, MR technology enables the simultaneous presentation of real and virtual objects to the user [49]. This immersive experience allows a user to seamlessly transition between the physical and virtual realms, forging an unparalleled level of presence and engagement.

The combination of mixed reality (MR) visualizations and artificial intelligence (AI) that incorporates machine learning, is garnering attention in the field of minimally invasive robotic surgery. Referred to as the surgical metaverse, this integration of MR and AI has the capability of facilitating surgical interventions to become simpler, more precise, and safer for patients [50].

2) ARTIFICIAL INTELLIGENCE (AI)

Pertains to the capacity of machines to emulate human intelligence, thus enabling them to exhibit human-like cognitive abilities and perform tasks with human-like proficiency [51]. AI comprises a range of subsets, with Machine Learning (ML), Natural Language Processing (NLP), and Computer Vision (CV). These individual technologies play a crucial role in assimilating AI into the metaverse.

The metaverse benefits significantly from Machine Learning (ML) technology as it allows it to learn from previous exchanges among participants and themselves, thereby leading to better results with time. This technology can also enhance the metaverse's ability to behave in a more human-like manner, reducing the need for human involvement and, as a result, opening new possibilities for scalability and expansion.

With Natural Language Processing (NLP) technology, the metaverse delivers an effortless user experience by converting natural language into computer-readable formats, which undergo analysis and processing to generate the expected outcome. Achieving optimal speech recognition accuracy requires integrating numerous AI technologies such as NLP, Neural Networks and Deep Learning. NLP technology enables the recognition and translation of natural language speech into a machine-language format, which is then subject to further processing and translation back into natural language.

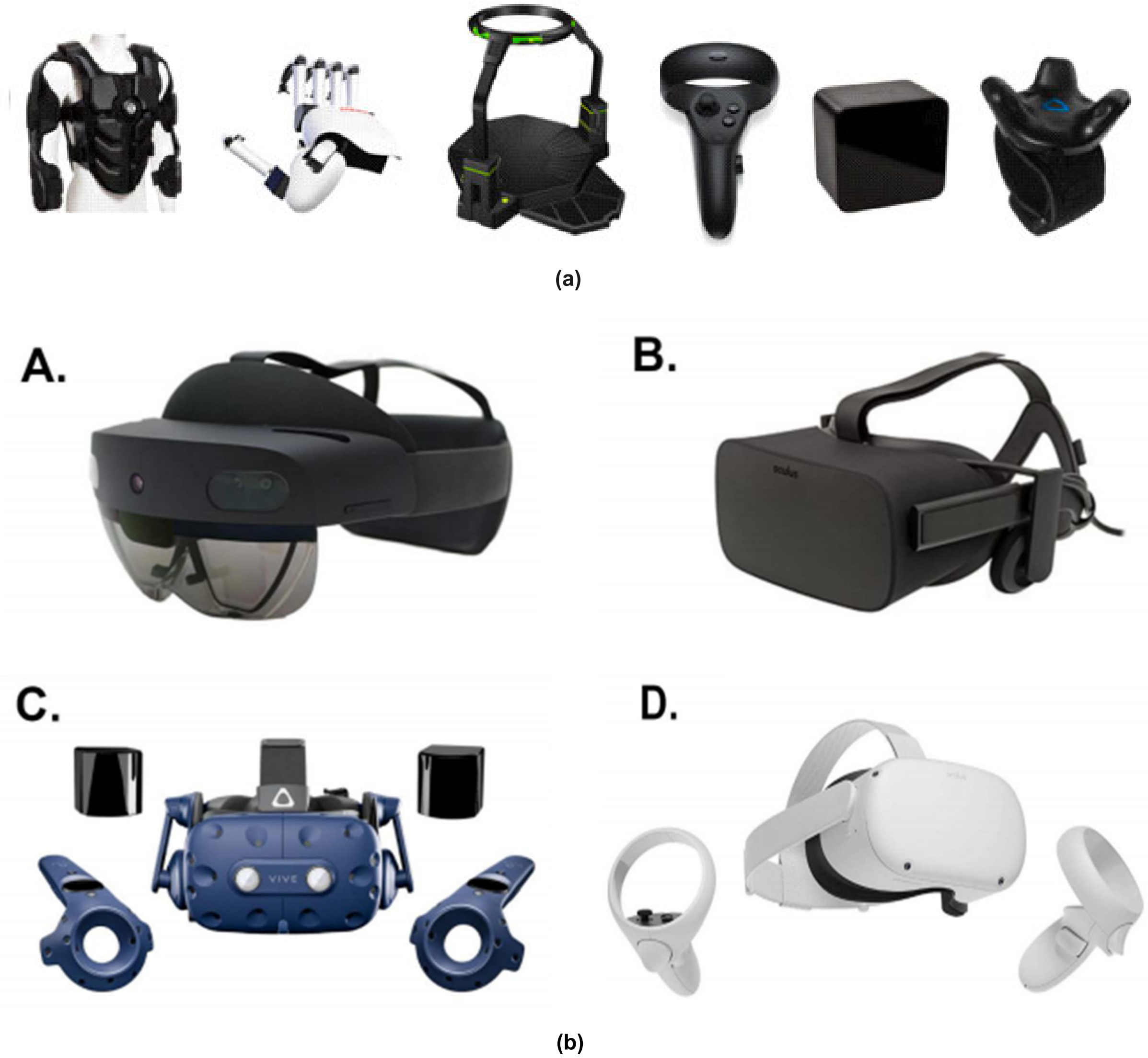

FIGURE 5. (a) VR accessories that provide an immersive experience (suit, haptic glove, omni-directional treadmill, motion sensor controller, lighthouse, tracker). (b) Popular VR Headsets: A. Microsoft HoloLens 2. B. Oculus Rift CV1. C. HTC Vive. D. Oculus Quest 2.

The metaverse benefits from this technology, which permits global user interaction and enables avatars to converse using a natural-sounding language.

Metaverse and AI have been proposed as metaverse of medical technology and AI (MeTAI) that can facilitate the growth, assessment, regulation, and refinement of AI-based medical practice, with virtual comparative scanning, raw data sharing, augmented regulatory science, and metaverse medical intervention as key elements [52].

3) DIGITAL TWINS (DT)

The notion of digital twins is centered on developing a comprehensive digital rendering of physical entities and systems [53]; it allows for the formation of digital replicas of actual physical entities [54], thereby facilitating precise forecasts and optimization of their virtual counterparts. The employment of advanced AI technology paves the way for the generation of true-to-life simulations of intricate physical processes, thereby providing significant benefits for creating and showcasing vast metaverse terrains. Moreover, digital twins offer preventive maintenance and monitoring of accidents, resulting in increased efficiency in the real world and a reduced risk of potential hazards. As a reflection of reality, the digital twin of the metaverse serves as a portal for users to explore and engage with virtual world services.

Digital Twins have the potential to be constructed on both micro and macro scales [55], with macroscopic DT reproducing the entirety of the universe. This replication allows for comprehensive exploration and plays a vital role in the construction of the Metaverse. In contrast, microscopic DT imitates molecular entities, providing a means to investigate phenomena at the subatomic level. This developmental progression highlights the adaptability of DTs in capturing diverse levels of intricacy, providing a versatile framework for understanding and modeling phenomena across various scales.

The emergence of Human Digital Twins (DT) as a promising research area involves the collection of real data from individuals and the use of machine learning (ML) to extract health-related insights, aiming to improve the understanding of human well-being [56]. However, a key challenge lies in acquiring this data without relying on uncomfortable and risky health-sensing devices. The implementation of DT technology for detailed human health applications is an important research gap. Bio-signals, including heart rate, breathing rate, blood oxygen saturation, and blood pressure, are crucial for diagnosing physical and psychological health conditions, such as emotions, fatigue, stress, and sleep patterns. These bio-signals are increasingly valuable for the adoption of virtual health and telemedicine services, which have gained momentum in the post-pandemic era.

4) TELECOMMUNICATION/INTER-NETWORKING

The metaverse accommodates an extensive user base through its capacity for global network connectivity via wireless networks. In recent times, numerous state-of-the-art technologies have surfaced intending to optimize the efficacy of networking systems and wireless communication. Artificial intelligence has been widely incorporated across multiple tiers of network infrastructure to facilitate this objective [57].

Data Networking Technologies, such as the Internet of Things (IoT), Software-Defined Networks (SDN), and Sixth Generation internet (6G), hold a pivotal position in enabling seamless and immediate dissemination of data between the physical and virtual realms, as well as among divergent sub-metaverses within the metaverse. The progressions in these state-of-the-art technologies, such as Beyond 5G (B5G) and 6G, furnish abundant possibilities for guaranteeing dependable, instantaneous, and extensive communication for multitudinous metaverse apparatus, with superior mobility capacities. Through the utilization of these technologies, the metaverse can achieve more substantial interconnectivity and wider availability, resulting in a smoother and more cohesive interaction for its users [58].

5) DECENTRALIZED LEDGER TECHNOLOGY - BLOCKCHAIN

By and large, blockchain denotes a distributed digital record that captures transactions and assets within a secure network utilizing cryptographic techniques [59]. This ledger ensures swift, universal, and transparent data, which is preserved in an immutable and impregnable structure that authorized network participants can solely enter. In the confines of the metaverse, copious amounts of data, including digital content and virtual reality videos, are frequently transported, and stored in data centers that inadequately prioritize security measures, rendering them susceptible to malicious cyber-attacks. However, with the implementation of blockchain technology, which boasts unparalleled characteristics, such as immutability and cryptographic security protocols, data privacy concerns within the metaverse can be effectively mitigated. While the current blockchain systems can record various activities, such as transactions and accounts, they can be modified to monitor metaverse data and content, ensuring a well-protected and confidential network for authorized participants [60].

Over the preceding decade, many methods have been proposed for collecting, conserving, and disseminating data, focusing on integrating blockchain and AI across a wide range of domains to guarantee the utmost data privacy and security. These innovative approaches have demonstrated considerable potential for implementation within the metaverse.

The integration of Metaverse and Blockchain technologies has the potential to revolutionize healthcare information systems by enabling the secure dissemination of sensitive patient data to relevant stakeholders. To ensure the veracity of information recipients, authentication and identification protocols may be devised [61]. The proposal [62] centers on utilizing blockchain technology to decentralize patient record sharing among diverse parties, thereby safeguarding data integrity and security.

6) CLOUD STORAGE AND COMPUTING

Cloud Storage and computing is an innovative solution that offers a wide array of computing services such as hosts, data storage, data repositories, networking infrastructure, software tools, data analytics, and intelligence via the Internet, also known as "the cloud." This approach is highly advantageous due to its capacity to facilitate faster innovation, flexible resources, and economies of scale. Metaverse technology can also benefit from cloud computing by enabling users to effortlessly monitor and analyze extensive data volumes without having to worry about device storage limitations [63].

IV. METAVERSE AND HEALTHCARE

The healthcare industry has long recognized the crucial role of continual physical interaction with patients to gauge their physical and emotional well-being. However, the advent of the COVID-19 pandemic has unapologetically disrupted this process, leaving healthcare providers at a loss for alternative solutions. The industry increasingly turns to remote care technologies, such as telehealth, which capitalizes on digital information and communication technologies to render healthcare services from a distance [63].

A study [7] suggests that before the outbreak of COVID-19, a mere 43% of healthcare facilities in the United States were equipped to facilitate telehealth services; however, by 2020, this figure had skyrocketed to 95% [26]. Telemedicine, an all-encompassing term for employing technological mediums to enable communication between physicians and patients without physical proximity, may take various forms, such as telephone calls, video conferences, electronic mail, and messaging [64]. Telemedicine is synonymous with digital medicine, e-health, telehealth, and m-health.

The concept of "MEDverse" is simultaneously evolving and holds great potential for revolutionizing the field of medical science. As telemedicine and remote care technologies like telehealth continue to gain traction in the healthcare industry, integrating the metaverse into medicine offers even greater possibilities for advancing patient outcomes, improving access to care, and enhancing collaboration among healthcare professionals [65], [66]. The creation of virtual healthcare environments not only provides a secure and accessible platform for patients, particularly in the post-COVID-19 era, but it also offers opportunities for medical professionals to synergize, share knowledge, and advance the field of medicine. Furthermore, the metaverse presents a promising avenue for mitigating the healthcare predicaments plaguing rural, remote, and disaster-stricken regions, allowing patients to receive immediate clinical attention in their homes and circumventing the challenges posed by an arduous journey to a hospital [67].

A. PHASES OF MEDICAL METAVERSE DEVELOPMENT

Implementation of Metaverse in Medicine has been outlined by [68]. The study suggests expanding the holographic construction process to include comprehensive perception, which means considering a wider range of factors when creating the holographic environment. It also proposes increasing holographic simulation to include intelligent processing, allowing for more sophisticated simulations. Additionally, the study suggests expanding the integration between virtual and real environments to include quality control and human-machine linkage. The goal is to improve the quality and effectiveness of Metaverse in Medicine by incorporating advanced technologies and approaches. Fig. 6. (a) describes the general process of developing a metaverse via four phases whereas. Fig. 6. (b) presents a holistic all-encompassing and more compelling proposition, showcasing the potential of a robust medical Metaverse constructed through holographic technology. This approach incorporates holographic construction techniques, immersive holographic simulations, the seamless merging of virtual and real worlds, and the seamless integration of virtual and physical environments. Fig. 6 (b) shows a medical Metaverse-enabled system that seamlessly blends the virtual and real realms. Within this, a cloud data center serves as the hub, hosting three vital servers: the AI medical image server, the holographic distribution server, and the consultant server. These interconnected components enable medical experts stationed at different hospitals to access a comprehensive repository of AI medical images and data using AR/VR glasses. By leveraging this advanced infrastructure, healthcare professionals can collaborate effectively in telemedicine, streamline radiological analysis, and facilitate the flow of AI-assisted case images.

1) HOLOGRAPHIC CONSTRUCTION

The initial step would involve creating a fixed geometric representation of the simulated world, encompassing medical facilities, apparatus, and other items. The objects can be categorized into three key components: persons, scenes, and events. A surgical setting can be a typical example where the indoor space and medical apparatus make up the "scene," while patients and healthcare professionals represent "people." Events pertaining to the kinetic information and data emanating from the exchanges occur among people, between individuals, or with the surroundings.

Holographic construction holds the potential for enhancing medical practice [68]. Comprehensive perception, achieved through advanced technologies like sensors and diagnostic tests, generates a holistic information map of physiological and pathophysiological alterations. This enables the creation of digital-twin stand-ins in the metaverse, integrating virtual and real realms. However, utilizing the Metaverse in Medicine poses challenges due to human anatomy and disease complexities. Yet, classifying medical cases and simplifying matters through consensus guidelines reveal its promise.

2) HOLOGRAPHIC SIMULATION

Holographic simulation holds promise for medical use, particularly when combined with intelligent processing. The expanded Metaverse in medicine focuses on enhancing teaching and training efficiency. Holographic simulations offer immersive learning experiences, like understanding the effects of smoking on lung cancer. They also aid in training complex medical techniques, such as endoscopic surgery. Moreover, the integration of artificial intelligence technology assists in addressing clinical challenges, enabling intelligent diagnosis and treatment.

3) FUSION OF REAL AND VIRTUAL WORLDS

As computer simulation technology progresses, digital technology will augment the verisimilitude of the virtual world of medicine.

Consequently, the differentiation between the virtual and physical realms will become increasingly nebulous, particularly in constructing a mixed reality (MR) world for medical purposes. In an outpatient setting, for example, a clinician can communicate with a patient who is donning an XR device. The capacity for instantaneous recognition, tracking, and information exchange will enable the retrieval of patient data, which can then be presented as augmented reality, generating a novel rapport with the extant natural environment.

4) REAL-VIRTUAL LINKAGES

The advancement of Artificial intelligence (AI), brain-computer interfaces (BCI), computer simulation technology, and other technologies will lead to the creation of new medical methods, equipment, and facilities. As technology develops, the processes of medical interventions in the real world will also change.

These changes will gradually lead to more intersections between medical interventions in the real and digital worlds, eventually leading to the rise of novel notions and techniques

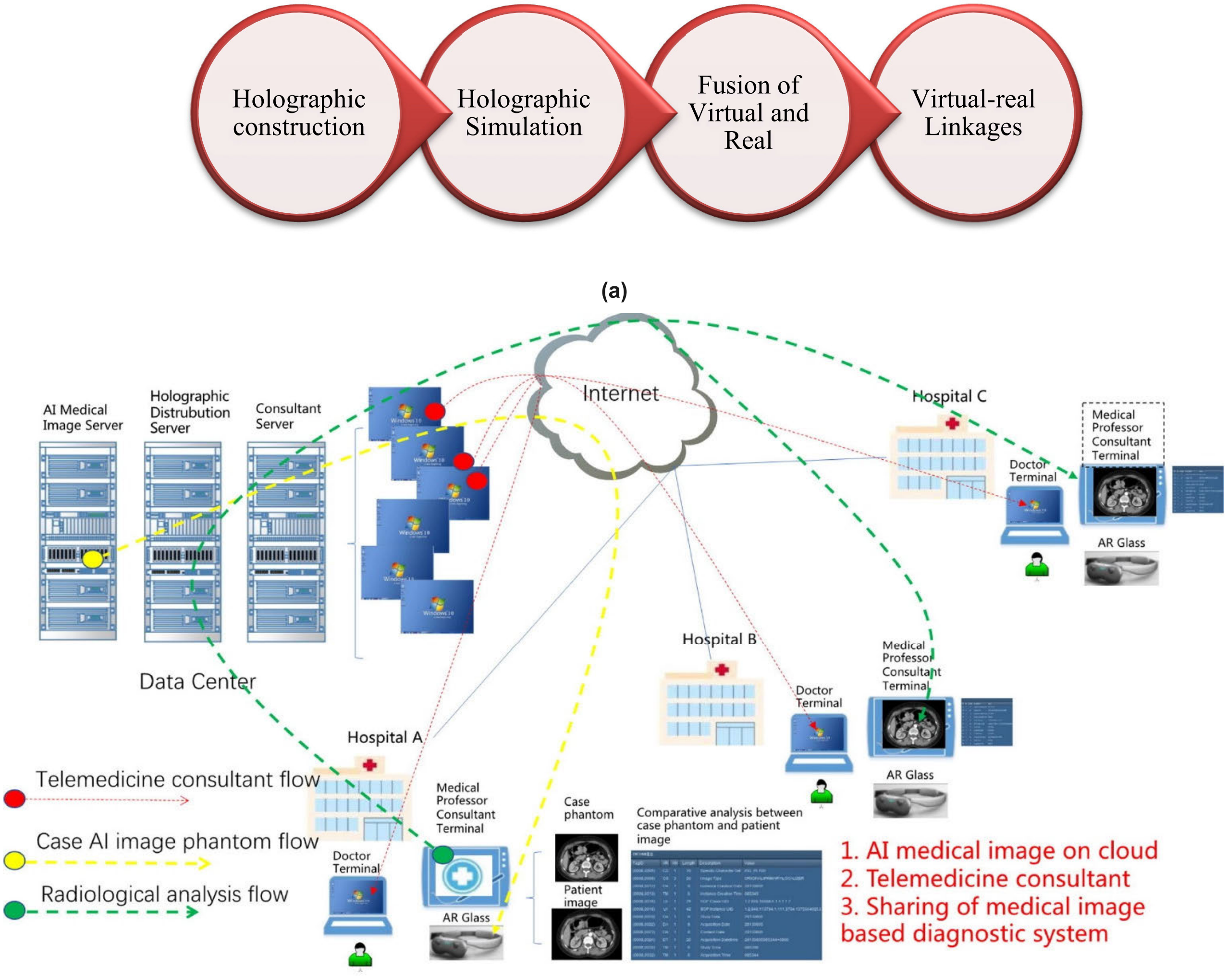

FIGURE 6. **(a) A general process of four phases of the implementation of the Medical Metaverse. (b) A feasible medical Metaverse built on holographic construction, holographic simulation, the merging of virtual and real worlds, and linking virtual and real environments [68].**

during the age of meta medicine. The meta-medical realm will complement and enhance the medical procedures executed in the real world. Meta-medicine enables us to perceive the physical realm through the prism of the informational sphere and modify the physical realm through the informational realm. Meta-medicine will have three key characteristics that set it apart from traditional medicine.

B. ROLE OF METAVERSE IN MEDICAL EDUCATION AND TRAINING

The Metaverse can overhaul how people are trained by providing augmented reality and other virtual elements to enhance learning in high-stress environments. Adding virtual features allows learning to be accomplished in less time, with greater student involvement and efficiency [69]. This could lead to a shift from traditional 2D books to interactive 3D teaching at virtual universities. With the limitations of current virtual education systems exposed by the Covid-19 pandemic, technologies used in the Metaverse offer opportunities to improve educational systems. The Metaverse provides students with realistic experiences of physical-world learning scenarios without constraints.

In healthcare education, the Metaverse will be utilized to provide hands-on learning possibilities for students to practice surgical and patient interactions, as well as novel procedures. It has the potential to aid in medical training by enhancing the educational process and fostering the acquisition of intricate clinical abilities [70]. Fig. 7 shows virtual reality experience is facilitated using various screens, allowing for collaborative learning in a group setting. Also, reactions of the simulated patient's pupils to light stimuli can be observed.

1) MEDICAL TRAINING

The advent of the Metaverse has unveiled novel avenues for medical training, prompting scholars to envision a prospective metamorphosis of the Metaverse into a virtual educational institution. Within this virtual realm, medical instructors would have the capacity to adeptly impart knowledge to students, focusing on complex topics [71]. Certain scholars have been actively developing an e-learning paradigm for virtual classrooms. In their recent publication, scholars [72] proposed that there is a prospect that the Metaverse could transform into a virtual educational institution, enabling medical instructors to impart knowledge to students about the complexities of the circulatory system. As a result, this could supersede traditional medical technologies such as Smartphones, chatbots, and telehealth systems. Recently, at the University of Northampton, nursing students have been allowed to hone their skills through a state-of-the-art VR simulation suite (See fig. 7 (e)). The suite features a large projection screen allowing group instruction, displaying a comprehensive view of what learners see in their VR environment [73]. This immersive experience provides a valuable tool for nursing students to develop their abilities and understand medical concepts in a more practical, hands-on way.

Similarly, midwifery students at the University of Newcastle in Australia are given a unique opportunity to learn about the complexities of pregnancy, which helps them thoroughly understand common pregnancy-related issues, such as breach positioning and placenta placement [12]. The research team has created a virtual reality (VR) technology that provides a comprehensive and detailed visualization of a realistic 3D figure during pregnancy without any limitations on the visual display. The use of both VR and MR technologies in this system makes it the first to illustrate all stages of childbirth. It is available on several platforms, including PC, Mac, Android, iOS, Microsoft HoloLens, and HTC Vive (figure. 5(b)) and provides a user-friendly experience for learners. Using a user-controlled virtual scrollbar on a tablet, hand controller in VR, or hand gestures in VR, students can easily browse through the different weeks of pregnancy, ranging from the first to the forty-second week. This facilitates an engaging and instinctive learning experience [74], [75].

In addition, the MOOG Simodont VR haptic dental simulator [76] is utilized for dental training and furnishes verisimilar haptic force feedback predicated on the admittance control paradigm. It responds to the user's applied force, engendering a sense of palpable engagement with an object of commensurate mass. The Simodont Dental Trainer's computer-screen exhibits high-definition imagery of dental equipment and teeth with 3D projection and a tangible handpiece with a virtual tip is employed to execute dental contouring procedures with verisimilar sound reproduction. Equipment encompasses a physical foot pedal to adjust the rotational speed virtual handpiece. Moreover, the simulator is fortified by software that chronicles real-time kinematics and contains manual dexterity exercises and operational dental procedures of varying complexity. The software was employed to instruct and appraise the participants' rudimentary manual dexterity abilities utilizing similar dental equipment. Those who received haptic device input from a professional dentistry teacher demonstrated accelerated progress compared to those who had access solely to the device or instructor-alone feedback.

2) EMERGENCY RESPONSE LEARNING

The Metaverse, an immersive technology, is also emerging as a promising tool for emergency medicine education, as it provides trainees with an unparalleled experience that can aid in developing critical teamwork, decision-making, and resuscitation skills [69]. This technology is instrumental in preparing healthcare specialists for handling mass casualty incidents, where the ability to make quick and informed decisions can make all the difference in saving lives.

An innovative cardiopulmonary resuscitation (CPR) system has been developed by [77], which allows medical trainees to acquire a range of critical skills, including utilizing an automated external defibrillator (AED), chest Compression and rescue breathing via a VR platform. By incorporating the HTC VIVE and Unity 3D software development, this system provides a unique blend of computer-produced interactive scenarios, tutorials, demonstrations, and practical training, to deliver an immersive and engaging learning experience. To ensure accuracy and precision in measuring chest compression rates, depths, the position of hands, recoil, and AED, a tracking system is built using virtual planes and VIVE-Tracker. The system also features a lifelike mannequin presented in the virtual environment and superimposed with a virtual 3D human model to offer accurate haptic feedback and practical training. Furthermore, the VIVE controller offers precise coordination between the physical location of the mannequin and the digital representation of the model in the virtual environment. In addition to CPR, this system includes demonstrations on performing a nasopharyngeal swab test and the proper disposal of personal protective equipment (PPE) kits in a virtual classroom within the CVRSB platform [78].

The Gordon center for simulation and innovation in medical education has recently initiated the integration of emergency management training employing AR, VR, and MR platforms for the optimal preparation of healthcare personnel in responding to exigent medical scenarios, including, but not limited to, stroke, heart attack, and arrhythmia. As a quintessential instance of the Gordon center's innovative healthcare simulation efforts, Harvey, the cardiopulmonary patient simulator that was formulated in 1968, functions as a virtual environment that emulates diverse cardiac pathologies encompassing blood pressure, pulse rate, respiration, heart sounds, murmurs, and respiratory diseases.

Similarly, the Inselspital, University Hospital Bern in Switzerland has adopted VR simulations as a practical and powerful mechanism in the Department of Emergency Medicine for instructing medical students in COVID-19 clinical diagnostics [79]. The students receive COVID-19-specific training, encompassing various relevant

(a) (b)

FIGURE 7. a) A nursing student donning a virtual reality headset. b) A simulated cardiac assessment is being performed on a virtual patient. c) Utilizing a variety of screens to display VR experience to facilitate collaborative learning in a group setting. d) Reactions of the simulated patient's pupils to light stimuli. e) Nursing facility located at the University of Northampton is aiding in the advancement of classroom learning [73].

skills, through the utilization of the COVID-19 VR Strikes Back (CVRSB) module, which is a VR-based medical training application created by ORamaVR SA, using the Oculus Rift (see figure. 5(b)) headset and hand controllers [78], [80].

3) HANDS-ON EXPERIENCE IN ANATOMY LEARNING

Traditionally, an understanding of the human body's anatomy was gained through the dissection of organisms. Therefore, anatomy knowledge is a cornerstone for medical practitioners, as it is impossible to repair or treat the body without understanding its normal and abnormal structure (in the case of diseases). Consequently, anatomy plays a vital role in comprehending how the body functions normally and abnormally. However, technology has revolutionized how we learn and teach anatomy, and now we have the luxury of metaverse applications to aid us in this process. These innovative tools provide an exciting and interactive way for students and practitioners to learn and improve their understanding of human anatomy.

The NU of Singapore's Yong Loo Lin School of Medicine has collaborated with Microsoft and the NUHS to develop an innovative three-dimensional holographic system, Project Polaris [12].

The primary objective of this project is to provide medical students with a more comprehensive understanding of anatomical features and to teach them crucial medical procedures. Microsoft HoloLens 2 is employed in training, which allows undergraduate medical and nursing students to acquire a higher level of proficiency. The Project Polaris training program immerses students in an augmented reality experience that offers an unparalleled visual awareness of real-world clinical settings, including cannula and catheter placement in both male and female urinary tracts. This approach provides students with an opportunity to enhance their abilities, which can have a significant impact on their future careers.

Similarly, GigXR and Elsevier have established a collaborative effort to fashion an innovative mixed-reality anatomy application known as HoloHuman, which allows learners to engage with holographic learning environments [82]. By making use of Microsoft HoloLens headgear and mobile devices, the application enables in-class and remote participation to interact during an active HoloHuman session. The application's sophisticated 3D holographic view provides detailed information regarding specific body parts, ultimately leading to a more profound understanding of human anatomy. Instructors have the flexibility to personalize models and textual labels, which can be saved for future use. In addition, the software's remote functionalities and compatibility with mobile devices ensure its ability to accommodate large classrooms while maintaining optimal teaching efficacy. Fig. 8. shows that 3D holographic learning environments are being produced through the utilization of HoloHuman.

Overall, the undertaken and similar studies [82], [83], [84], [85] indicate that immersive virtual reality can improve trainees' motor skills, including bodily movements, navigation, orientation, and decision-making abilities, which can aid in eliminating unconscious biases. Likewise, immersive VR enhances the trainees' task performance by facilitating faster learning with fewer errors compared to training with actual physical equipment. Metaverse immersive VR has the potential to facilitate improved evaluation and preparation in the design and testing stages by allowing engineers and users

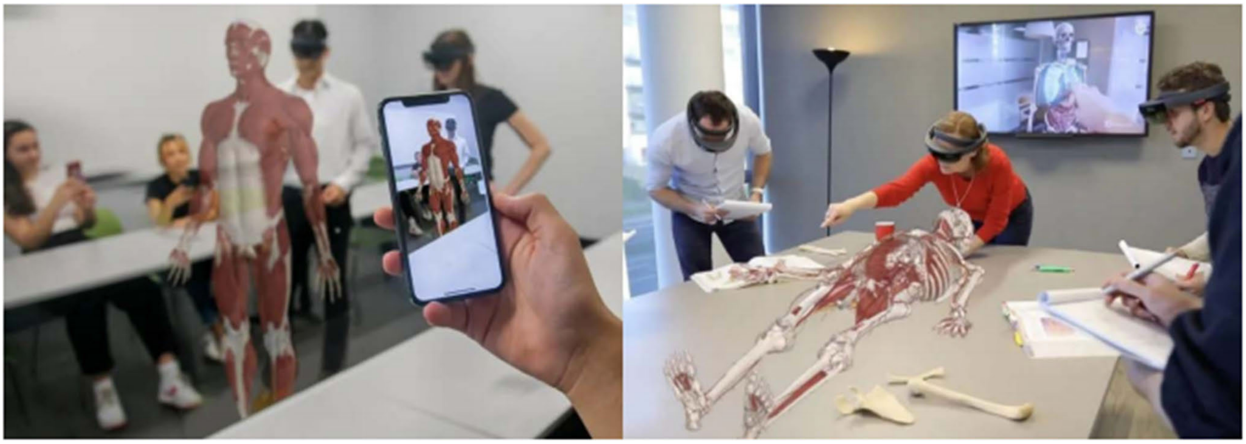

FIGURE 8. 3D holographic learning environments are being produced through the utilization of HoloHuman [81].

to interact more effectively with various components using virtual prototypes [86].

4) HANDS-ON EXPERIENCE IN SURGERY

The development of surgical simulators has emerged alongside the metaverse. These simulators offer a valuable tool for training surgical students and provide the ability to plan and prepare for intricate procedures. Additionally, surgical simulators generate structured data that can be used to create algorithms for computer-assisted treatments that rely on medical imaging.

One of the studies in this domain [87] discusses the limitations of conventional pre-operative counseling methods and identifies various barriers that hamper effective communication between patients and surgeons. These barriers include insufficient motivation, inadequate conversational abilities of the physician, and linguistic disparities. The study proposes that the metaverse can solve the inefficacy of current counseling methods. Comprehension of surgical procedures, risks, and complications can be improved by presenting them virtually, resulting in more practical knowledge and a comprehensive understanding, which enhances the patient's ability to retain information. This helps patients make informed decisions without coercion, which leads to higher patient satisfaction.

Other applications for surgical training include the use of VR simulations to train orthopaedic surgery residents in arthroplasty, which is a surgical procedure aimed at restoring the function of a joint, such as training for total hip arthroplasty [88]. One study [50] suggests the combination of augmented reality and artificial intelligence in robotic surgery, known as the surgical metaverse. A control tower is necessary for processing digital data, and guidance strategies and movement correction can improve accuracy.

C. METAVERSE FOR INDIVIDUAL MEDICAL DOMAINS

The Metaverse offers a multitude of possibilities in the realm of healthcare, spanning from research and physical examinations to diagnosis and clinical care. Now we will delve into some specific applications Metaverse can offer to the healthcare industry.

1) ORTHOPEDICS

Orthopedics is concerned with preserving and maintaining the functionality of the skeletal system, encompassing the joints, muscles, and spine.

John Hopkins neurosurgeons have used augmented reality to perform surgeries on patients with chronic back pain and malignant tumors in the spine [12]. Based on CT scans, the technology uses a headset with a clear display to project visualizations of the patient's internal anatomy, such as bones and other tissues. This technology gives surgical specialists a real-time view of the patient's anatomy during the surgery, eliminating the need for repeated glances at a separate screen.

Similarly, research [70] discusses how the Metaverse can be employed in medical education and training, patient management, and clinical care, focusing on orthopaedics and rehabilitation, disciplines related to musculoskeletal health problems. The research further underlines the different components of the Metaverse, including virtual and augmented reality, and their applications in various medical settings, such as training students in clinical skills used in rare situations, improving the safety of clinicians performing invasive processes, and facilitating remote teaching.

2) OBSTETRICS

Metaverse is a non-pharmacological technique to help pregnant women reduce anxiety levels during pregnancy and control pain during labor, thereby reducing negative medical, physiological, psychological, and behavioral effects on both the mother and child [89]. Some studies [90], [91] aim to utilize different Metaverse technologies, such as VR techniques and 3D modeling, to alleviate anxiety and stress levels experienced by pregnant women during various stages of pregnancy and labor. Such studies focus on educating pregnant women about medical procedures, providing virtual contact between the mother and her fetus, and diverting patients' attention away from pain signals during pregnancy.

Similarly, another study [92] discusses the potential use of Metaverse technology in fetal medicine and gynecology for training specialists and facilitating multidisciplinary discussions without geographical obstacles.

3) NEUROLOGY

SyncThink's Eye-Sync VR headset is a Metaverse application that can assist in treating and diagnosing brain impairments, specifically in athletes who have experienced concussions [93]. Eye-Sync is based on VR and eye-tracking technology, which allows it to monitor and record eye movement data. By detecting abnormalities in visual performance and eye movement, Eye-Sync can contribute to the recovery process of patients with brain impairments.

4) ONCOLOGY

There are several Metaverse use-case scenarios in cancer treatment as well. Metaverse has numerous potential applications in various areas of medicine, including cancer care. One study [66] on the subject discusses the utilization of augmented reality/VR technologies in surgical treatment and cancer rehabilitation, as well as the potential for telemedicine services through avatar-based consultations. Similarly, another study [94] discusses the evolving treatment options for patients with metastatic hormone-sensitive prostate cancer (mHSPC), particularly the use of triple therapy with docetaxel chemotherapy and androgen receptor signaling inhibitors (ARSIs) in addition to androgen deprivation therapy (ADT). The author highlights the importance of identifying patient subgroups most likely to benefit from treatment intensification to optimize treatment while minimizing harm and added costs.

5) DENTISTRY

Several studies aim to explore the potential of using metaverse technology in various dental applications. They demonstrate that metaverse technology can be used for effective pain management and to improve the accuracy and precision of surgical procedures [95]. For instance, the technology can provide virtual simulations of dental surgeries, assist in the treatment of lesions in the cavernous sinus region by accurately describing the 3D anatomical structure, aid in characterizing the tumor's deep extension into the orbital roof during tumor removal [96], develop an effective navigation strategy for distraction osteogenesis in patients, assess the effectiveness of mandibular restorations, and analyze the surgical transfer of virtual orthognathic planning. Another research pertains to the conceivable utilization of metaverse technology within the domain of dentistry, with a particular focus on oral hygiene education, dental anxiety, and dental trauma [97]. Through the employment of this technology, juveniles can effectively participate in a virtual world that facilitates the acquisition of oral hygiene techniques while simultaneously decreasing dental anxiety. Moreover, metaverse technology can inform patients about dental trauma and the requisite measures to undertake during such episodes. The passage accentuates the sundry studies that have investigated this topic and underscore how this technology may potentially disrupt the landscape of dentistry.

6) MENTAL HEALTH

Research studies in mental health have predominantly focused on investigating the efficacy of exposure-based therapies. These therapies are commonly used to treat phobias and anxiety-related mental health conditions.

Such treatments involve creating a secure environment and gradually exposing patients to the stimuli that elicit their fears, thereby aiding them in conquering their apprehensions. One such method is Virtual Reality Exposure Therapy (VRET) [111], which simulates fear-inducing stimuli in a safe and controlled environment. This study analyzes the advantages and disadvantages of using VRET in treating specific phobias. Another study suggests a virtual reality exposure treatment for veterans with post-traumatic stress disorder (PTSD) [112]. The immersive treatment involves exposing patients to various virtual environments, including a middle eastern-themed setting and is shown to be an effective way to help veterans deal with trauma.

Similarly, an alternative study [113] relevant to the subject matter analyzes tweets related to the Metaverse concept and its potential impact on mental health. The study used Twitter's API to collect tweets related to mental health issues and keywords related to the Metaverse. After analyzing the tweets, the study found that about one-third of individuals expressed neutral sentiments towards the Metaverse and its potential impact on mental health, one-third suggested that the Metaverse could be used as a tool for improving mental health and well-being, and one-third self-reported that the Metaverse could worsen pre-existing mental illnesses. The study concludes that further research is needed to explore the potential positive impact of the Metaverse on mental health and the need for mental health education within the Metaverse.

Similarly, the authors in [114] aim to address the increasing cases of mental illness treatment in the metaverse space caused by the development of related industries and the COVID-19 pandemic. The authors propose to use a game engine to create a high-realistic virtual diagnosis and treatment stage based on the metaverse, which can help reduce patients' discomfort and provide a more active psychotherapy atmosphere. By utilizing physically based rendering and building a more intelligent and visualized digital therapy stage, the study seeks to establish a highly realistic and effective digital therapy treatment in the future. Moreover, the research [115] found that mental health issues are prevalent in the eSport industry, particularly in China, where the trend has increased. Video gaming strategies are used for training, but preventive measures are needed to address gaming addiction. The research highlights the impact of metaverse-based digital healthcare on eSport performance and the importance of

TABLE 2. A summary of Metaverse and its application in various medical-related fields.

Operational sphere	Description	Authors
Senior Care	Discussing challenges and Offering opportunities for social interaction to senior citizens	[98, 99]
Vascular System Fitness	The uses of metaverse technology concerning cardiovascular health.	[72, 100]
Prolonged and Chronic Diseases	Controlling long-term illnesses	[101, 102]
Dentistry	Discussing the applications of a metaverse in dentistry	[97, 103]
Gynecology	The uses of metaverse technology in gynecology and the health of the fetus	[89, 92] [90, 91]
Oncology	Possible uses of the metaverse in the context of treating cancer	[66, 94, 104]
Ophthalmology	Prospects and obstacles in vision care.	[105]
Mental health	Potential uses of the metaverse for addressing mental health.	[106-108]
Physical health	Potential uses of the metaverse for addressing Physical health.	[109]
Medical education and training	Tools that facilitate the sharing of information, clinical simulation, and healthcare delivery.	[8, 69, 110] [70, 72] [12, 73] [74-76] [69, 77, 78]
Emergency	Applications of the metaverse on emergency care	[69]

considering mental health and digital personality in this context.

7) PHYSICAL HEALTH

Within the realm of physical health, research has predominantly centered on programs to enhance users' physical performance and manage pain. The findings indicate positive results in areas such as posture, balance, gait, strength, and cognitive improvements. However, physiological and psychological outcomes did not show any notable improvements. Many of the virtual reality programs that were employed for rehabilitation and exercise purposes took a game-like approach. Encouragingly, immersive VR has been found to significantly alleviate pain symptoms [109].

Table 2 presents a meta-analysis of the use of metaverse services in the healthcare industry. The analysis identifies 11 different areas where these services are applied and provides descriptions and author information for each. Most of the studies reviewed were conducted within the past year or two.

V. OPEN CHALLENGES TO THE METAVERSE IMPLEMENTATION IN HEALTHCARE

The implementation of the Metaverse within the healthcare sector presents a unique opportunity to revolutionize patient health monitoring services through the incorporation of interactive virtual features. Utilizing advanced technologies such as VR for medical training and AR during surgical procedures, the Metaverse has the potential to transform the way individuals interact with healthcare systems. However, despite its promising potential, this innovative solution is not without its challenges. Some of them are discussed below.

A. DATA AND INFORMATION PRIVACY AND SECURITY

The collection and monitoring of personal data raise significant concerns regarding the privacy and security of patients [64]. Given the potential for malicious users to exploit vulnerabilities and gain access to sensitive information, creating "clone clouds" and "private copies" may provide an effective solution to preserve user privacy at various levels, including sensory, communication, and behavioral aspects [116].

B. IDENTITY HACKING

As we enter the era of the metaverse, there are concerns about establishing identity and authenticity in virtual spaces. The use of avatars can lead to challenges in verifying a person's identity, as bots can easily imitate human behavior and personality. Therefore, it is essential to have various authentication procedures, such as biometric scans and speech recognition, to confirm the user's identity [117]. However, the creation of virtual duplicates of humans in the metaverse can be used for illicit purposes such as spreading false information or identity theft. Moreover, privacy and security issues may arise, as hackers can access personal information and exchange sensitive data while in virtual space. Hence, it is crucial to consider these issues while developing the metaverse.

C. LEGAL ISSUES

The Metaverse, with its vast potential for virtual malfeasance and regulatory complexities, will necessitate novel legal and regulatory frameworks to ensure the proper governance and security of its operations. The advent of the Metaverse in the healthcare sector has the potential to furnish numerous advantages to patients and medical professionals but also carries latent legal and regulatory concerns [118]. The dearth of established guidelines and standards could engender bewilderment among various stakeholders, comprising healthcare providers, insurance firms, and pharmaceutical companies, concerning issues of intellectual property rights and issues of trust. Therefore, it becomes indispensable to promulgate appropriate policies within the legal framework to manage illicit activities in the virtual domain and ensure a secure and streamlined service for patients.

D. INTEROPERABILITY

The exchange of electronic patient information among healthcare providers and systems is becoming increasingly complex with the growth of healthcare data and modern technology. The integration of the Metaverse in healthcare poses additional challenges, as it requires the combination of various hardware and software components with wearable technology in a virtual environment. To prevent any negative consequences while migrating devices from traditional healthcare services to the virtual world, it is necessary to establish proper communication standards and data adoption strategies to ensure the consistency and security of sensitive information.

VI. FUTURE DIRECTIONS

The Metaverse harbors the potential to bring about a paradigm shift in the healthcare industry by providing all-encompassing healthcare services. This can be realized by employing virtual communication between specialists and end-users, coupled with the dispensation of a wide range of medical services such as disease prevention, diagnosis, and treatment to name a few. However, there are certain future arenas to work on to make the metaverse more feasible for adoption in the healthcare industry.

A. BLOCKCHAIN TECHNOLOGY: A PROMISING FUTURE FOR HEALTHCARE RECORD STORAGE AND INTEGRATION

With its potential to enhance the efficiency of record storage, empower individual control, and overcome fragmented systems, blockchain technology emerges as a promising avenue for healthcare, particularly in the realm of medical record storage. By capitalizing on its decentralized nature, blockchain enables secure storage of records within personal blockchain wallets, thereby offering numerous advantages such as heightened security, streamlined accessibility, and the ability to authorize global clinician access. Furthermore, by fostering collaboration among healthcare providers, blockchain holds the capability to address the complex nature of multifaceted health conditions, ultimately leading to the realization of a more integrated healthcare system. As a result, the adoption of blockchain in healthcare presents itself as a crucial and exciting future direction for research in the realms of the metaverse, blockchain, and healthcare, offering immense potential to revolutionize the industry, improve patient outcomes, and surmount existing challenges.

Additionally, in the future, blockchain and gamification can be used to incentivize learners through tokens or NFT crypto collectables for attending events or completing extracurricular activities. The metaverse can also host various teaching activities, conferences, seminars, and public engagement events. AR and VR approaches along with machine learning tools can provide hyper-realistic simulations, real-world training, and instant feedback for surgical procedures and training simulations.

B. ADDRESSING PRIVACY CONCERNS IN METAVERSE-BASED HEALTHCARE SOLUTIONS

The Metaverse enhances user experiences by merging physical and virtual realms through communication and virtual technologies. It can monitor physiological responses and collect personal information from patients, but privacy and security concerns arise. Innovative solutions like the "clone cloud" and "private copy" can protect against malicious exploitation and data leaks. Emphasizing privacy measures is crucial in developing Metaverse-based healthcare solutions, encompassing sensory, communication, and behavioral aspects. Further research in this field can unlock the transformative potential of the Metaverse in healthcare.

Metaverse integrates hardware, software components, and wearable devices in a virtual environment, ensuring the security and consistency of sensitive information becomes paramount. To overcome challenges, it is crucial to develop robust communication standards and effective data adoption strategies.

C. EXPLORING AN ORCHESTRATED EDGE-CLOUD METAVERSE ARCHITECTURE

The conventional server-centric network architecture utilized in the Metaverse poses significant challenges, including high latency and data loss, which ultimately undermine the user experience. To effectively tackle this issue and fully unleash the potential of Metaverse technology within the healthcare domain, it becomes imperative to look into a future research direction that concentrates on the development of an orchestrated edge-cloud Metaverse architecture. This novel approach entails the dynamic distribution of computation and communication among multiple entities within the network. Through the implementation of such an architecture, notable enhancements can be achieved in the quality of service and user experience for healthcare applications.

VII. CONCLUSION

The healthcare industry faces challenges due to limited resources, funding constraints, and geographic barriers that hinder access to care. Leveraging the capabilities of the metaverse in healthcare can lead to cost reductions, redirecting resources to areas like advanced screening technologies. The global healthcare market in the metaverse is expected to reach 71.97 billion dollars by 2030 [2], reflecting significant growth potential. This presents an opportunity to transform the industry, improving access, cost-effectiveness, and patient care. To this end, the undertaken study provides a comprehensive evaluation of academic discussions and research related to the Metaverse, the healthcare industry, and emerging technologies. Its objective is to explore how the Metaverse can revolutionize healthcare in the future. To establish a strong foundation, the study delves into the fundamentals of the Metaverse and its potential applications in various medical domains. These applications range from enhancing medical education and training to enabling immersive clinical care, performing surgical procedures, supporting obstetrics and so on.

The shifting mindset, characterized by the increased adoption of telehealth and the influence of gaming on younger generations, reflects a growing acceptance of technology in healthcare, as has been revealed by the study. As we strive for proactive healthcare, technologies like virtual reality (VR), blockchain, and digital twins play a significant role in transforming the healthcare landscape. However, while recognizing the potential of the Metaverse in improving healthcare, it is vital to approach its implementation with a focus on preserving the quality of care and ensuring patient safety. Moreover, it is crucial to acknowledge and address the impact on the human dimension of healthcare when integrating technology. The ethical and practical considerations surrounding data security and privacy, interoperability challenges, and legal complexities associated with data ownership and distribution must be carefully navigated. By proactively addressing these challenges, we can ensure that the implementation of Metaverse systems aligns with the principles of quality care and patient safety.

By emphasizing a patient-centered approach and maintaining a comprehensive understanding of the potential risks and benefits, we can effectively harness the power of the Metaverse in healthcare. This requires a thoughtful and conscientious approach, where technology acts as an enabler rather than a disruptor. Through this approach, we can maximize the benefits of the Metaverse in improving healthcare outcomes while safeguarding the well-being and interests of patients.

REFERENCES

[1] G. Salloum and J. Tekli, "Automated and personalized nutrition health assessment, recommendation, and progress evaluation using fuzzy reasoning," *Int. J. Hum.-Comput. Stud.*, vol. 151, Jul. 2021, Art. no. 102610.

[2] R. Chengoden, N. Victor, T. Huynh-The, G. Yenduri, R. H. Jhaveri, M. Alazab, S. Bhattacharya, P. Hegde, P. K. R. Maddikunta, and T. R. Gadekallu, "Metaverse for healthcare: A survey on potential applications, challenges and future directions," *IEEE Access*, vol. 11, pp. 12765–12795, 2023.

[3] Y. Lu, D. Yang, Y. Yang, and C. Bai, "MIoT integrates health, MM benefits humans: Funding conference for international association and alliance of metaverse in medicine successfully held," *Clin. eHealth*, vol. 5, pp. 17–18, Dec. 2022.

[4] M. Alshamrani, "IoT and artificial intelligence implementations for remote healthcare monitoring systems: A survey," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 8, pp. 4687–4701, Sep. 2022.

[5] A. Kapoor, S. Guha, M. K. Das, K. C. Goswami, and R. Yadav, *Digital Healthcare: The Only Solution for Better Healthcare During COVID-19 Pandemic*, vol. 72. Amsterdam, The Netherlands: Elsevier, 2020, pp. 61–64.

[6] T. Shakeel, "A survey on COVID-19 impact in the healthcare domain: Worldwide market implementation, applications, security and privacy issues, challenges and future prospects," *Complex Intell. Syst.*, vol. 9, no. 1, p. 1027-1058, 2022.

[7] J. Thomason, "Metahealth-how will the metaverse change health care?" *J. Metaverse*, vol. 1, no. 1, pp. 13–16, 2021.

[8] D. Holloway, "Virtual worlds and health: Healthcare delivery and simulation opportunities," in *Virtual Worlds and Metaverse Platforms: New Communication and Identity Paradigms*. Hershey, PA, USA: IGI Global, 2012, pp. 251–270.

[9] I. Skalidis, O. Muller, and S. Fournier, "The metaverse in cardiovascular medicine: Applications, challenges, and the role of non-fungible tokens," *Can. J. Cardiol.*, vol. 38, no. 9, pp. 1467–1468, Sep. 2022.

[10] S. Ali, T. P. T. Armand, A. Athar, A. Hussain, M. Ali, M. Yaseen, M.-I. Joo, and H.-C. Kim, "Metaverse in healthcare integrated with explainable AI and blockchain: Enabling immersiveness, ensuring trust, and providing patient data security," *Sensors*, vol. 23, no. 2, p. 565, Jan. 2023.

[11] A. Garavand and N. Aslani, "Metaverse phenomenon and its impact on health: A scoping review," *Informat. Med. Unlocked*, vol. 32, Jul. 2022, Art. no. 101029.

[12] G. Bansal, K. Rajgopal, V. Chamola, Z. Xiong, and D. Niyato, "Healthcare in metaverse: A survey on current metaverse applications in healthcare," *IEEE Access*, vol. 10, pp. 119914–119946, 2022.

[13] C. W. Lee, "Application of metaverse service to healthcare industry: A strategic perspective," *Int. J. Environ. Res. Public Health*, vol. 19, no. 20, Oct. 2022, Art. no. 13038.

[14] L. Petrigna and G. Musumeci, "The metaverse: A new challenge for the healthcare system: A scoping review," *J. Funct. Morphology Kinesiol.*, vol. 7, no. 3, p. 63, Aug. 2022.

[15] A. Liberati, "The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration," *Ann. Internal Med.*, vol. 151, no. 4, p. W-65, Aug. 2009.

[16] M. D. J. Peters, C. M. Godfrey, H. Khalil, P. McInerney, D. Parker, and C. B. Soares, "Guidance for conducting systematic scoping reviews," *Int. J. Evidence-Based Healthcare*, vol. 13, no. 3, pp. 141–146, 2015.

[17] S. Ali Haidery, H. Ullah, N. U. Khan, K. Fatima, S. S. Rizvi, and S. J. Kwon, "Role of big data in the development of smart city by analyzing the density of residents in Shanghai," *Electronics*, vol. 9, no. 5, p. 837, May 2020.

[18] Z. Ebrahimpour, W. Wan, O. Cervantes, T. Luo, and H. Ullah, "Comparison of main approaches for extracting behavior features from crowd flow analysis," *ISPRS Int. J. Geo-Inf.*, vol. 8, no. 10, p. 440, Oct. 2019.

[19] Q. Liu, H. Ullah, W. Wan, Z. Peng, L. Hou, T. Qu, and S. A. Haidery, "Analysis of green spaces by utilizing big data to support smart cities and environment: A case study about the city center of Shanghai," *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 6, p. 360, Jun. 2020.

[20] H. Ullah, W. Wan, S. Ali Haidery, N. U. Khan, Z. Ebrahimpour, and T. Luo, "Analyzing the spatiotemporal patterns in green spaces for urban studies using location-based social media data," *ISPRS Int. J. Geo-Inf.*, vol. 8, no. 11, p. 506, Nov. 2019.

[21] H. Ullah, W. Wan, S. A. Haidery, N. U. Khan, Z. Ebrahimpour, and A. A. M. Muzahid, "Spatiotemporal patterns of visitors in urban green parks by mining social media big data based upon WHO reports," *IEEE Access*, vol. 8, pp. 39197–39211, 2020.

[22] N. Stephenson, *Snow Crash: A Novel*. Irvine, CA, USA: Spectra, 2003.

[23] M. U A. Babu and P. Mohan, "Impact of the metaverse on the digital future: People's perspective," in *Proc. 7th Int. Conf. Commun. Electron. Syst. (ICCES)*, Jun. 2022, pp. 1576–1581.

[24] T. Huynh-The, Q.-V. Pham, X.-Q. Pham, T. T. Nguyen, Z. Han, and D.-S. Kim, "Artificial intelligence for the metaverse: A survey," 2022, *arXiv:2202.10336*.

[25] J. Lee, I. Yeo, and H. Lee, "Metaverse current status and prospects: Focusing on metaverse field cases," in *Proc. IEEE/ACIS 7th Int. Conf. Big Data, Cloud Comput., Data Sci. (BCD)*, Aug. 2022, pp. 332–336.

[26] A. Elhence, V. Kohli, V. Chamola, and B. Sikdar, "Enabling cost-effective and secure minor medical teleconsultation using artificial intelligence and blockchain," *IEEE Internet Things Mag.*, vol. 5, no. 1, pp. 80–84, Mar. 2022.

[27] K. Lippert, M. N. R. Khan, M. M. Rabbi, A. Dutta, and R. Cloutier, "A framework of metaverse for systems engineering," in *Proc. IEEE Int. Conf. Signal Process., Inf., Commun. Syst. (SPICSCON)*, Dec. 2021, pp. 50–54.

[28] I. Nikolaidis, "Networking the metaverses," *IEEE Netw.*, vol. 21, no. 5, pp. 1–2, Sep. 2007.

[29] D. Owens, A. Mitchell, D. Khazanchi, and I. ZIgurs, "An empirical investigation of virtual world projects and metaverse technology capabilities," *ACM SIGMIS Database, DATABASE Adv. Inf. Syst.*, vol. 42, no. 1, pp. 74–101, Feb. 2011.

[30] R. Schroeder, A. Huxor, and A. Smith, "Activeworlds: Geography and social interaction in virtual reality," *Futures*, vol. 33, no. 7, pp. 569–587, Sep. 2001.

[31] F. Li, S. Papagiannidis, and M. Bourlakis, "Living in 'multiple spaces': Extending our socioeconomic environment through virtual worlds," *Environ. Planning D, Soc. Space*, vol. 28, no. 3, pp. 425–446, Jun. 2010.

[32] H.-S. Choi and S.-H. Kim, "A content service deployment plan for metaverse museum exhibitions—Centering on the combination of beacons and HMDs," *Int. J. Inf. Manage.*, vol. 37, no. 1, pp. 1519–1527, Feb. 2017.

[33] Y. K. Dwivedi, "Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *Int. J. Inf. Manage.*, vol. 66, Oct. 2022, Art. no. 102542.

[34] F. Guglielmucci, M. Monti, I. G. Franzoi, G. Santoro, A. Granieri, J. Billieux, and A. Schimmenti, "Dissociation in problematic gaming: A systematic review," *Current Addiction Rep.*, vol. 6, no. 1, pp. 1–14, Mar. 2019.

[35] S. Zhang, E. Dinan, J. Urbanek, A. Szlam, D. Kiela, and J. Weston, "Personalizing dialogue agents: I have a dog, do you have pets too?" 2018, *arXiv:1801.07243*.

[36] T. Kwanya, C. Stilwell, and P. Underwood, *Library 3.0: Intelligent Libraries and Apomediation*. Amsterdam, The Netherlands: Elsevier, 2014.

[37] C. Jaynes, W. B. Seales, K. Calvert, Z. Fei, and J. Griffioen, "The Metaverse: A networked collection of inexpensive, self-configuring, immersive environments," in *Proc. Workshop Virtual Environ.*, 2003, pp. 115–124.

[38] A. Çöltekin, I. Lochhead, M. Madden, S. Christophe, A. Devaux, C. Pettit, O. Lock, S. Shukla, L. Herman, Z. Stachoň, P. Kubíček, D. Snopková, S. Bernardes, and N. Hedley, "Extended reality in spatial sciences: A review of research challenges and future directions," *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 7, p. 439, Jul. 2020.

[39] A. Musamih, I. Yaqoob, K. Salah, R. Jayaraman, Y. Al-Hammadi, M. Omar, and S. Ellahham, "Metaverse in healthcare: Applications, challenges,and future directions," *IEEE Consum. Electron. Mag.*, vol. 12, no. 4, pp. 33–46, Jul. 2023.

[40] J. H. Steffen, J. E. Gaskin, T. O. Meservy, J. L. Jenkins, and I. Wolman, "Framework of affordances for virtual reality and augmented reality," *J. Manage. Inf. Syst.*, vol. 36, no. 3, pp. 683–729, Jul. 2019.

[41] J. Parong, K. A. Pollard, B. T. Files, A. H. Oiknine, A. M. Sinatra, J. D. Moss, A. Passaro, and P. Khooshabeh, "The mediating role of presence differs across types of spatial learning in immersive technologies," *Comput. Hum. Behav.*, vol. 107, Jun. 2020, Art. no. 106290.

[42] H. E. Hershfield, D. G. Goldstein, W. F. Sharpe, J. Fox, L. Yeykelis, L. L. Carstensen, and J. N. Bailenson, "Increasing saving behavior through age-progressed renderings of the future self," *J. Marketing Res.*, vol. 48, pp. S23–S37, Feb. 2011.

[43] C. Spence, M. Obrist, C. Velasco, and N. Ranasinghe, "Digitizing the chemical senses: Possibilities & pitfalls," *Int. J. Hum.-Comput. Stud.*, vol. 107, pp. 62–74, Nov. 2017.

[44] S. Badruddoja, R. Dantu, Y. He, M. Thompson, A. Salau and K. Upadhyay, "Trusted AI with blockchain to empower metaverse," in *Proc. 4th Int. Conf. Blockchain Comput. Appl. (BCCA)*, San Antonio, TX, USA, 2022, pp. 237–244, doi: 10.1109/BCCA55292.2022.9922027.

[45] L. Gout, A. Hart, C.-H. Houze-Cerfon, R. Sarin, G. R. Ciottone, and V. Bounes, "Creating a novel disaster medicine virtual reality training environment," *Prehospital Disaster Med.*, vol. 35, no. 2, pp. 225–228, Apr. 2020.

[46] M. F. Price, D. E. Tortosa, A. N. Fernandez-Pacheco, N. P. Alonso, J. J. C. Madrigal, R. Melendreras-Ruiz, Á. J. García-Collado, M. P. Rios, and L. J. Rodriguez, "Comparative study of a simulated incident with multiple victims and immersive virtual reality," *Nurse Educ. Today*, vol. 71, pp. 48–53, Dec. 2018.

[47] Z. Liu, L. Ren, C. Xiao, K. Zhang, and P. Demian, "Virtual reality aided therapy towards health 4.0: A two-decade bibliometric analysis," *Int. J. Environ. Res. Public Health*, vol. 19, no. 3, p. 1525, Jan. 2022.

[48] J. Gerup, C. B. Soerensen, and P. Dieckmann, "Augmented reality and mixed reality for healthcare education beyond surgery: An integrative review," *Int. J. Med. Educ.*, vol. 11, pp. 1–18, Jan. 2020.

[49] Y. Wang, Z. Su, N. Zhang, R. Xing, D. Liu, T. H. Luan, and X. Shen, "A survey on metaverse: Fundamentals, security, and privacy," *IEEE Commun. Surveys Tuts.*, vol. 25, no. 1, pp. 319–352, 1st Quart., 2023.

[50] F. W. van Leeuwen and J. A. van der Hage, *Where Robotic Surgery Meets the Metaverse*, vol. 14. Basel, Switzerland: Multidisciplinary Digital Publishing Institute, 2022, p. 6161.

[51] S. J. Russell, *Artificial Intelligence a Modern Approach*. London, U.K.: Pearson, 2010.

[52] G. Wang, "Development of metaverse for intelligent healthcare," *Nature Mach. Intell.*, vol. 9, pp. 922–929, Nov. 2022.

[53] N. H. Chu, D. T. Hoang, D. N. Nguyen, K. T. Phan, E. Dutkiewicz, D. Niyato, and T. Shu, "MetaSlicing: A novel resource allocation framework for metaverse," 2022, *arXiv:2205.11087*.

[54] I. Yaqoob, K. Salah, M. Uddin, R. Jayaraman, M. Omar, and M. Imran, "Blockchain for digital twins: Recent advances and future research challenges," *IEEE Netw.*, vol. 34, no. 5, pp. 290–298, Sep. 2020.

[55] Z. Lv, S. Xie, Y. Li, M. S. Hossain, and A. El Saddik, "Building the metaverse by digital twins at all scales, state, relation," *Virtual Reality Intell. Hardw.*, vol. 4, no. 6, pp. 459–470, Dec. 2022.

[56] I. Al-Zyoud, F. Laamarti, X. Ma, D. Tobón, and A. El Saddik, "Towards a machine learning-based digital twin for non-invasive human bio-signal fusion," *Sensors*, vol. 22, no. 24, p. 9747, Dec. 2022.

[57] M. Chen, U. Challita, W. Saad, C. Yin, and M. Debbah, "Artificial neural networks-based machine learning for wireless networks: A tutorial," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 4, pp. 3039–3071, 4th Quart., 2019.

[58] H. Du, D. Niyato, C. Miao, J. Kang, and D. I. Kim, "Optimal targeted advertising strategy for secure wireless edge metaverse," in *Proc. GLOBECOM IEEE Global Commun. Conf.*, Dec. 2022, pp. 4346–4351.

[59] T. R. Gadekallu, Q. Pham, D. C. Nguyen, P. K. R. Maddikunta, N. Deepa, B. Prabadevi, P. N. Pathirana, J. Zhao, and W. Hwang, "Blockchain for edge of things: Applications, opportunities, and challenges," *IEEE Internet Things J.*, vol. 9, no. 2, pp. 964–988, Jan. 2022.

[60] A. Cannavò and F. Lamberti, "How blockchain, virtual reality, and augmented reality are converging, and why," *IEEE Consum. Electron. Mag.*, vol. 10, no. 5, pp. 6–13, Sep. 2021.

[61] Q. Lu and X. Xu, "Adaptable blockchain-based systems: A case study for product traceability," *IEEE Softw.*, vol. 34, no. 6, pp. 21–27, Nov. 2017.

[62] H. Wu, Y. Shang, L. Wang, L. Shi, K. Jiang, and J. Dong, "A patient-centric interoperable framework for health information exchange via blockchain," in *Proc. 2nd Int. Conf. Blockchain Technol. Appl.*, Dec. 2019, pp. 76–80.

[63] Y.-T. Song and J. Qin, "Metaverse and personal healthcare," *Proc. Comput. Sci.*, vol. 210, pp. 189–197, Jan. 2022.

[64] P. Swider, *The Future of Healthcare & Patient Care in the Metaverse*. Accessed: Apr. 2023. [Online]. Available: https://accelerationeconomy.com/metaverse/the-future-of-healthcare-patient-care-in-the-metaverse/

[65] A. Cerasa, A. Gaggioli, F. Marino, G. Riva, and G. Pioggia, "The promise of the metaverse in mental health: The new era of MEDverse," *Heliyon*, vol. 8, no. 11, Nov. 2022, Art. no. e11762.

[66] Y. Zeng, L. Zeng, C. Zhang, and A. S. K. Cheng, "The metaverse in cancer care: Applications and challenges," *Asia–Pacific J. Oncol. Nursing*, vol. 9, no. 12, Dec. 2022, Art. no. 100111.

[67] V. Chamola, V. Hassija, S. Gupta, A. Goyal, M. Guizani, and B. Sikdar, "Disaster and pandemic management using machine learning: A survey," *IEEE Internet Things J.*, vol. 8, no. 21, pp. 16047–16071, Nov. 2021.

[68] D. Yang, J. Zhou, Y. Song, M. Sun, and C. Bai, "Metaverse in medicine," *Clin. eHealth*, vol. 5, pp. 39–43, Dec. 2022.

[69] T.-C. Wu and C.-T.-B. Ho, "A scoping review of metaverse in emergency medicine," *Australas. Emergency Care*, vol. 26, no. 1, pp. 75–83, Mar. 2023.

[70] J. M. Román-Belmonte, E. C. Rodríguez-Merchán, and H. D. la Corte-Rodríguez, "Metaverse applied to musculoskeletal pathology: Orthoverse and rehabverse," *Postgraduate Med.*, vol. 135, no. 5, pp. 440–448, Jul. 2023.

[71] I. Suh, T. McKinney, and K.-C. Siu, "Current perspective of metaverse application in medical education, research and patient care," *Virtual Worlds*, vol. 2, no. 2, pp. 115–128, Apr. 2023.

[72] B. Mesko, *The Promise of the Metaverse in Cardiovascular Health*. London, U.K.: Oxford Univ. Press, 2022.

[73] J. Pottle, "Virtual reality and the transformation of medical education," *Future Healthcare J.*, vol. 6, no. 3, pp. 181–185, Oct. 2019.

[74] D. Jones, "The road to birth: Using digital technology to visualise pregnancy anatomy," in *Digital Anatomy: Applications of Virtual, Mixed and Augmented Reality*. Cham, Switzerland: Springer, 2021, pp. 325–342.

[75] D. Jones, Z. S. See, M. Billinghurst, L. Goodman, and S. Fealy, "Extended reality for midwifery learning: MR VR demonstration," in *Proc. 17th Int. Conf. Virtual-Reality Continuum Appl. Ind.*, Nov. 2019, pp. 1–2.

[76] L. M. Al-Saud, F. Mushtaq, M. J. Allsop, P. C. Culmer, I. Mirghani, E. Yates, A. Keeling, M. A. Mon-Williams, and M. Manogue, "Feedback and motor skill acquisition using a haptic dental simulator," *Eur. J. Dental Educ.*, vol. 21, no. 4, pp. 240–247, Nov. 2017.

[77] O. Almousa, J. Prates, N. Yeslam, D. M. Gregor, J. Zhang, V. Phan, M. Nielsen, R. Smith, and K. Qayumi, "Virtual reality simulation technology for cardiopulmonary resuscitation training: An innovative hybrid system with haptic feedback," *Simul. Gaming*, vol. 50, no. 1, pp. 6–22, Feb. 2019.

[78] P. Zikas, M. Kamarianakis, I. Kartsonaki, N. Lydatakis, S. Kateros, M. Kentros, E. Geronikolakis, G. Evangelou, A. Apostolou, P. A. A. Catilo, and G. Papagiannakis, "COVID-19–VR strikes back: Innovative medical VR training," in *Proc. ACM SIGGRAPH Immersive Pavilion*, Aug. 2021, pp. 1–2.

[79] T. Birrenbach, J. Zbinden, G. Papagiannakis, A. K. Exadaktylos, M. Müller, W. E. Hautz, and T. C. Sauter, "Effectiveness and utility of virtual reality simulation as an educational tool for safe performance of COVID-19 diagnostics: Prospective, randomized pilot trial," *JMIR Serious Games*, vol. 9, no. 4, Oct. 2021, Art. no. e29586.

[80] P. Zikas, S. Kateros, N. Lydatakis, M. Kentros, E. Geronikolakis, M. Kamarianakis, G. Evangelou, I. Kartsonaki, A. Apostolou, T. Birrenbach, A. K. Exadaktylos, T. C. Sauter, and G. Papapagiannakis, "Virtual reality medical training for COVID-19 swab testing and proper handling of personal protective equipment: Development and usability," *Frontiers Virtual Reality*, vol. 2, p. 175, Feb. 2022.

[81] *Gigxr and Elsevier Unveil Expanded Remote Features for Their Holohuman 3D Immersive Anatomy App*. Accessed: Mar. 2023. [Online]. Available: https://www.auganix.org/gigxr-and-elsevier-unveil-expanded-remote features-for-their-holohuman-3d-immersive-anatomy-app/

[82] C. Zammit, J. Calleja-Agius, and E. Azzopardi, "Augmented reality for teaching anatomy," *Clin. Anatomy*, vol. 35, no. 6, pp. 824–827, Jun. 2022.

[83] K. Bogomolova, I. J. M. Ham, M. E. W. Dankbaar, W. W. Broek, S. E. R. Hovius, J. A. Hage, and B. P. Hierck, "The effect of stereoscopic augmented reality visualization on learning anatomy and the modifying effect of visual-spatial abilities: A double-center randomized controlled trial," *Anatomical Sci. Educ.*, vol. 13, no. 5, pp. 558–567, Sep. 2020.

[84] S. Küçük, S. Kapakin, and Y. Göktaş, "Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load," *Anatomical Sci. Educ.*, vol. 9, no. 5, pp. 411–421, Oct. 2016.

[85] M. Ma, P. Fallavollita, I. Seelbach, A. M. Von Der Heide, E. Euler, J. Waschke, and N. Navab, "Personalized augmented reality for anatomy education," *Clin. Anatomy*, vol. 29, no. 4, pp. 446–453, May 2016.

[86] T. Strohmann, D. Siemon, and S. Robra-Bissantz, "Designing virtual in-vehicle assistants: Design guidelines for creating a convincing user experience," *AIS Trans. Hum.-Comput. Interact.*, vol. 11, no. 2, pp. 54–78, 2019.

[87] A. Anwer, Y. Jamil, and M. Bilal, "Provision of surgical pre-operative patient counseling services through the metaverse technology," *Int. J. Surg.*, vol. 104, Aug. 2022, Art. no. 106792.

[88] J. Hooper, E. Tsiridis, J. E. Feng, R. Schwarzkopf, D. Waren, W. J. Long, L. Poultsides, W. Macaulay, G. Papagiannakis, E. Kenanidis, E. D. Rodriguez, J. Slover, K. A. Egol, D. P. Phillips, S. Friedlander, and M. Collins, "Virtual reality simulation facilitates resident training in total hip arthroplasty: A randomized controlled trial," *J. Arthroplasty*, vol. 34, no. 10, pp. 2278–2283, Oct. 2019.

[89] S. Hajesmaeel-Gohari, F. Sarpourian, and E. Shafiei, "Virtual reality applications to assist pregnant women: A scoping review," *BMC Pregnancy Childbirth*, vol. 21, no. 1, pp. 1–8, Dec. 2021.

[90] L. Noben, S. M. T. A. Goossens, S. E. M. Truijens, M. M. G. van Berckel, C. W. Perquin, G. D. Slooter, and S. J. van Rooijen, "A virtual reality video to improve information provision and reduce anxiety before cesarean delivery: Randomized controlled trial," *JMIR Mental Health*, vol. 6, no. 12, Dec. 2019, Art. no. e15872.

[91] A. Sridhar, Z. Shiliang, R. Woodson, and L. Kwan, "Non-pharmacological anxiety reduction with immersive virtual reality for first-trimester dilation and curettage: A pilot study," *Eur. J. Contraception Reproductive Health Care*, vol. 25, no. 6, pp. 480–483, Nov. 2020.

[92] H. Werner, G. Ribeiro, V. Arcoverde, J. Lopes, and L. Velho, "The use of metaverse in fetal medicine and gynecology," *Eur. J. Radiol.*, vol. 150, May 2022, Art. no. 110241.

[93] V. Sundaram, V. Y. Ding, M. Desai, A. Lumba-Brown, and J. Little, "Reliable sideline ocular-motor assessment following exercise in healthy student athletes," *J. Sci. Med. Sport*, vol. 22, no. 12, pp. 1287–1291, Dec. 2019.

[94] H. E. Dzimitrowicz and A. J. Armstrong, "Triplet therapy: Entering the metaverse of metastatic hormone-sensitive prostate cancer treatment," *Eur. Urol.*, vol. 82, no. 6, pp. 599–601, Dec. 2022.

[95] M. Qu, Y. Hou, Y. Xu, C. Shen, M. Zhu, L. Xie, H. Wang, Y. Zhang, and G. Chai, "Precise positioning of an intraoral distractor using augmented reality in patients with hemifacial microsomia," *J. Cranio-Maxillofacial Surg.*, vol. 43, no. 1, pp. 106–112, Jan. 2015.

[96] P. Scolozzi and P. Bijlenga, "Removal of recurrent intraorbital tumour using a system of augmented reality," *Brit. J. Oral Maxillofacial Surg.*, vol. 55, no. 9, pp. 962–964, Nov. 2017.

[97] S. Duman, D. Çelik Özen, and Ş. B. Duman, "Metaverse in paediatric dentistry," *Eur. Arch. Paediatric Dentistry*, vol. 23, no. 4, pp. 655–656, Aug. 2022.

[98] M.-G. Cho, "A study on smart aging system for the elderly based on metaverse," *J. Digit. Converg.*, vol. 20, no. 2, pp. 261–268, 2022.

[99] R. A. Nugroho, S. G. Prakoso, K. N. Hidayati, A. D. Rahmawati, A. T. Kartinawanty, and S. A. Santoso, "Challenges of the metaverse adoption for the health of the elderly: Case in surakarta," in *Proc. IEEE Int. Conf. Comput. Sci. Inf. Technol. (ICOSNIKOM)*, Oct. 2022, pp. 1–6.

[100] I. Skalidis, O. Müller, and S. Fournier, "CardioVerse: The cardiovascular medicine in the era of metaverse," *Trends Cardiovascular Med.*, doi: 10.1016/j.tcm.2022.05.004.

[101] M. Sun, L. Xie, Y. Liu, K. Li, B. Jiang, Y. Lu, Y. Yang, H. Yu, Y. Song, C. Bai, and D. Yang, "The metaverse in current digital medicine," *Clin. eHealth*, vol. 5, pp. 52–57, Dec. 2022.

[102] M. K. Southworth, J. R. Silva, and J. N. A. Silva, "Use of extended realities in cardiology," *Trends Cardiovascular Med.*, vol. 30, no. 3, pp. 143–148, Apr. 2020.

[103] K. I. Afrashtehfar and A. S. H. Abu-Fanas, "Metaverse, crypto, and NFTs in dentistry," *Educ. Sci.*, vol. 12, no. 8, p. 538, Aug. 2022.

[104] A. McWilliam and P. Scarfe, "The metaverse and oncology," *Clin. Oncol.*, vol. 35, no. 1, pp. 12–14, Jan. 2023.

[105] T. F. Tan, Y. Li, J. S. Lim, D. V. Gunasekeran, Z. L. Teo, W. Y. Ng, and D. S. Ting, "Metaverse and virtual health care in ophthalmology: Opportunities and challenges," *Asia–Pacific J. Ophthalmol.*, vol. 11, no. 3, pp. 237–246, 2022.

[106] A. Almarzouqi, A. Aburayya, and S. A. Salloum, "Prediction of user's intention to use metaverse system in medical education: A hybrid SEM-ML learning approach," *IEEE Access*, vol. 10, pp. 43421–43434, 2022.

[107] C. Turbyne, "Virtuality technologies in mental healthcare: The medical metaverse of tomorrow," M.S. Thesis, Universiteit van Amsterdam, Amsterdam, The Netherlands, 2022.
[108] S. S. Usmani, M. Sharath, and M. Mehendale, "Future of mental health in the metaverse," *Gen. Psychiatry*, vol. 35, no. 4, Aug. 2022, Art. no. e100825.
[109] V. Smith, R. R. Warty, J. A. Sursas, O. Payne, A. Nair, S. Krishnan, F. da Silva Costa, E. M. Wallace, and B. Vollenhoven, "The effectiveness of virtual reality in managing acute pain and anxiety for medical inpatients: Systematic review," *J. Med. Internet Res.*, vol. 22, no. 11, Nov. 2020, Art. no. e17980.
[110] T. D. Parsons, "Virtual simulations and the second life metaverse: Paradigm shift in neuropsychological assessment," in *Virtual Worlds and Metaverse Platforms: New Communication and Identity Paradigms*. Hershey, PA, USA: IGI Global, 2012, pp. 234–250.
[111] M. Slater, C. Gonzalez-Liencres, P. Haggard, C. Vinkers, R. Gregory-Clarke, S. Jelley, Z. Watson, G. Breen, R. Schwarz, W. Steptoe, D. Szostak, S. Halan, D. Fox, and J. Silver, "The ethics of realism in virtual and augmented reality," *Frontiers Virtual Reality*, vol. 1, p. 1, Mar. 2020.
[112] A. Rizzo, A. Hartholt, M. Grimani, A. Leeds, and M. Liewer, "Virtual reality exposure therapy for combat-related posttraumatic stress disorder," *Computer*, vol. 47, no. 7, pp. 31–37, Jul. 2014.
[113] C. Krittanawong, A. Isath, C. L. Katz, S. Kaplin, Z. Wang, M. Ma, E. A. Storch, J. Torous, S. R. Ellis, and C. J. Lavie, "Public perception of metaverse and mental health on Twitter: A sentiment analysis," *Prog. Cardiovascular Diseases*, vol. 76, pp. 99–101, Jan. 2023.
[114] Y. Han and S. Oh, "Investigation and research on the negotiation space of mental and mental illness based on metaverse," in *Proc. Int. Conf. Inf. Commun. Technol. Converg. (ICTC)*, Oct. 2021, pp. 673–677.
[115] L. Cai, Z. Huang, Q. Feng, X. Chang, and K. Yan, "Co-transformation of digital health and eSport in metaverse: Moderating effects of digital personality on mental health in multiplayer online battle arena (MOBA)," *Int. J. Environ. Res. Public Health*, vol. 20, no. 1, p. 760, Dec. 2022.
[116] B. Falchuk, S. Loeb, and R. Neff, "The social metaverse: Battle for privacy," *IEEE Technol. Soc. Mag.*, vol. 37, no. 2, pp. 52–61, Jun. 2018.
[117] V. Hassija, V. Chamola, B. C. Bajpai, and S. Zeadally, "Security issues in implantable medical devices: Fact or fiction?" *Sustain. Cities Soc.*, vol. 66, Mar. 2021, Art. no. 102552.
[118] M. Gordon. *The Metaverse: What are Legal Implications*. Accessed: Apr. 2023. [Online]. Available: https://www.cliffordchance.com/insights/resources/blogs/talking-tech/en/articles/2022/02/the-metaverse–what-are-the-legal-implications-.html

HIDAYAT ULLAH received the master's degree from Preston University, Islamabad, Pakistan, in 2015. He is currently pursuing the Ph.D. degree with the School of Communication and Information Engineering, Shanghai University, Shanghai, China. He has authored nine SCI-indexed articles in internationally renowned journals. He was involved in several research projects, including projects of the National Natural Science Foundation of China and the Shanghai Science and Technology Commission. He was also a member of the Institute of Smart City, Shanghai University. He received the CSC Scholarship (China Scholarship Council) to study with Shanghai University; and the Turkey Burslari Scholarship in Istanbul Sabahattin Zaim University, Istanbul, Turkey, for his postdoctoral certificate, from 2021 to 2023. His research interests include big data, social media, environmental science, smart city, urban planning, and metaverse. He was the Co-Chair of the IEEE Conference ICALIP 2017.

SELVAKUMAR MANICKAM is an Associate Professor and a Researcher with the National Advanced IPv6 Centre (NAv6), Universiti Sains Malaysia, working in cybersecurity, the Internet of Things, industry 4.0, and machine learning. He has supervised 13 Ph.D. students. He has ten years of industrial experience before joining academia. He also has experience in building IoT, embedded, server, mobile, and web-based applications. He has authored or coauthored more than 160 articles in journals, conference proceedings, and book reviews. He is a member of technical forums at national and international levels.

MUATH OBAIDAT (Senior Member, IEEE) is an Associate Professor of computer science and information security with the John Jay College of Criminal Justice, The City University of New York (CUNY); a member of the Center for Cybercrime Studies; the Graduate Faculty Member of the Master of Science Digital Forensics and Cyber Security Program; and the Doctoral Faculty Member of the Computer Science Department, Graduate School and University Center of CUNY. He has published numerous scientific articles in journals and reputed conference proceedings. His research interests include digital forensics, ubiquitous Internet of Things (IoT), and security and privacy. His current research crosscuts the areas of wireless network protocols and cloud computing and it's security.

SHAMS UL ARFEEN LAGHARI received the B.Sc. (Hons.) and M.Sc. degrees in computer science from the University of Sindh, Jamshoro, Pakistan, and the M.S. degree in computer science from PAF-KIET, Karachi, Pakistan. He is currently pursuing the Ph.D. degree in network security with the National Advanced IPv6 Centre, Universiti Sains Malaysia. His research interests include network security, industry 4.0, distributed systems, cloud computing, and mobile cloud computing.

MUEEN UDDIN (Senior Member, IEEE) received the degree from Universiti Teknologi Malaysia (UTM), in 2013. He is currently an Associate Professor of data and cybersecurity with the University of Doha for Science and Technology, Qatar. He has published more than 130 international journals and conference papers in highly reputed journals with a cumulative impact factor of over 300. His research interests include blockchain, cybersecurity, the IoT security, and network and cloud security.