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SURVEY

Healthcare in Metaverse: A Survey on Current Metaverse Applications in Healthcare

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ABSTRACT The COVID-19 pandemic has revealed several limitations of existing healthcare systems. Thus, there is a surge in healthcare innovation and new business models using computer-mediated virtual environments to provide an alternative healthcare system. Today, digital transformation is not limited to virtual communication alone but encompasses digitalizing the network of social connections in the healthcare industry using metaverse technology. The metaverse is a universal and immersive virtual world facilitated by virtual reality (VR) and augmented reality (AR). This paper presents the first effort to offer a comprehensive survey that examines the latest metaverse developments in the healthcare industry, which covers seven domains: telemedicine, clinical care, education, mental health, physical fitness, veterinary, and pharmaceuticals. We review metaverse applications and deeply discuss technical issues and available solutions in each domain that can help develop a self-sustaining, persistent, and future-proof solution for medical healthcare systems. Finally, we highlight the challenges that must be tackled before fully embracing the metaverse for the healthcare industry.

INDEX TERMS Metaverse, healthcare, IoT, AI, machine learning, blockchain, AR/VR, 6G, networking.

I. INTRODUCTION

Increasing healthcare costs, colossal infrastructure costs, fast-aging populations, and a shortage of healthcare personnel have proved that healthcare systems are unsustainable for the future [1]. The COVID-19 pandemic has compelled healthcare providers and innovators to seek solutions for managing patients outside the hospitals. As a result, it is essential to establish models that relocate health care away from the hospital into the living room of the patients [2], [3]. With the rise of technologies, telemedicine and telehealth have made it possible to communicate with doctors without being in the same room. However, the virtualization of the healthcare industry is far more intricate. Researchers have been working on hospital virtualization in the metaverse. The word ''Metaverse'' was initially used in Neal Stephenson's 1992 novel ''Snow Crash'' [4]. Stephenson defines the metaverse in the novel as a vast virtual environment that coexists with the physical world and in which people converse through digital avatars. A ''metaverse'' is a three-dimensional shared virtual space in which users may carry out all actions via the use of augmented reality (AR), mixed reality (MR) and virtual reality (VR) technology (Figure 1).

Today the metaverse has emerged as a popular idea. In brief, the metaverse is often characterized as a future version of the Internet. Using augmented reality (AR), virtual reality (VR), and extended reality (XR), users will traverse the virtual worlds of the metaverse in a manner similar to how

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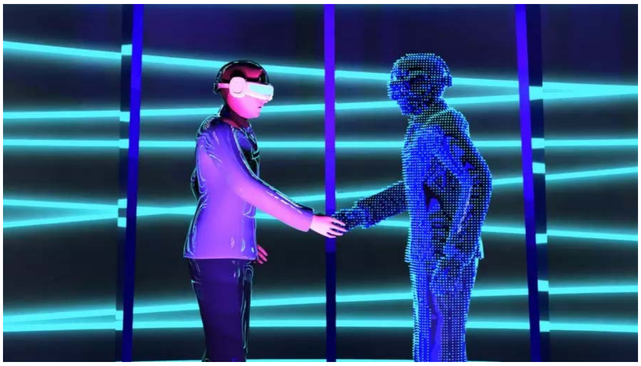

FIGURE 1. Metaverse (combination of AR, VR and MR technologies) [9].

we surf online sites with a mouse cursor nowadays. To date, companies like Google, Microsoft, and Meta have spent significantly developing the metaverse as "the successor to the internet connectivity." In the future, the metaverse will succeed the Internet in transforming innovative ecosystems of service supply in all fields, including healthcare, education, entertainment, e-commerce, and smart industries [5], [6], [7], [8], [9], [10]. Recently, Facebook was renamed "Meta" as it reinvents itself from a "social media" business to a "Metaverse" company in order to strengthen its dedication to the establishment of the metaverse. Meta is currently developing immersive hybrid glasses that allow to reproduce the user's real body using wearable sensors in metaverse. Metaverse is thus influencing cognitive processes and letting the users experience the sense of presence, i.e., the feeling of "being there" [10], [11], [12].

There are two major motivating elements behind the metaverse's popularity:

1) First, the Covid-19 epidemic has caused a paradigm change in how work, enjoyment, and social interaction are perceived today. As more people get acclimated to these traditionally physical actions in the virtual realm, the metaverse has been positioned as an imminent requirement.
2) Secondly, emerging technical enablers have increased the likelihood of the metaverse. 5G/6G communication systems enable users to be visually and physically engaged in a virtual environment while using AR/VR and haptic technologies. Metaverse makes the digital identity of each person in virtual reality analogous to their physical selves using avatars. These avatars have an alternative existence in virtuality that serves as a metaphor for the users' actual realities and replicates their physical counterparts' attributes [13], [14].

Today metaverse can be employed to solve issues in healthcare systems. Metaverse enables real-world applications to achieve the highest degrees of experience-duality, including shared, open, and endless virtual worlds. The metaverse would make interoperability across platforms representing various virtual worlds possible, allowing users to develop and share content between virtual worlds. A user may, for instance, produce content in one clinic/hospital and transfer it to another clinic/hospital while maintaining their identity. [15] highlights the caution required when embracing the concept of the metaverse as it forms key narratives driving technological design and global policy. He highlights that the metaverse is meant to establish a seamless integration with the existing physical reality. Realizing the metaverse depends on the advancement of AR, VR, AI, high-speed networks, edge computing, and hyper ledgers (or blockchain) [16], [17], [18], [19]. These technologies serve as building blocks of the metaverse. Having discussed the prospects of the metaverse in the healthcare industry, it is imperative also to understand the challenges that need to be tackled before wide adoption of the metaverse is possible such as identity hacking, hardware limitation, etc. In this survey paper, we discuss the technical details of some of the metaverse applications used in healthcare, highlighting their strengths and challenges.

The significant contributions of the article are:

1) This survey serves as a significant effort to offer a comprehensive view of the metaverse in the healthcare industry.
2) By reviewing the state-of-the-art metaverse applications in different domains of the healthcare industry, such as clinical care, veterinary, education, and physical fitness, the article reflects the value that metaverse can add to the current healthcare industry.
3) We propose research challenges based on our findings that need to be tackled before the wide adoption of metaverse technology in the healthcare industry.

This survey is organized as follows. The motivation and the rationale behind the applications of the metaverse are established in the Introduction (Section I). In Section II, we discuss related works that are currently existing in the literature. Section III discusses the background information required for understanding of metaverse. The following sections (Sections IV - X) discuss the application of metaverse in different healthcare domains: telemedicine, education, clinical care, mental health, physical wellness, veterinary, and pharmaceuticals. The numerous challenges that need to be handled before the wide-scale acceptance of metaverse in the healthcare industry are discussed in Section XI. Finally, the survey provides a conclusion in Section XII. For better readability, the overview of the survey is presented in figure 2.

II. RELATED WORKS

As the popularity of the metaverse in the domain of healthcare has been increasing rapidly, multiple surveys on the application of metaverse in various medical fields have appeared recently. Table 1 provides an overview of existing surveys and how our survey adds additional value.

In 2021, Thomas et al. studied the impact of metaverse on the healthcare industry in [20]. The work primarily focuses on five areas: collaborative working, education, clinical care, wellness, and monetization. The work gave a broad but general knowledge of what the future of the metaverse would be like. In our work, we extend the work by focusing on other

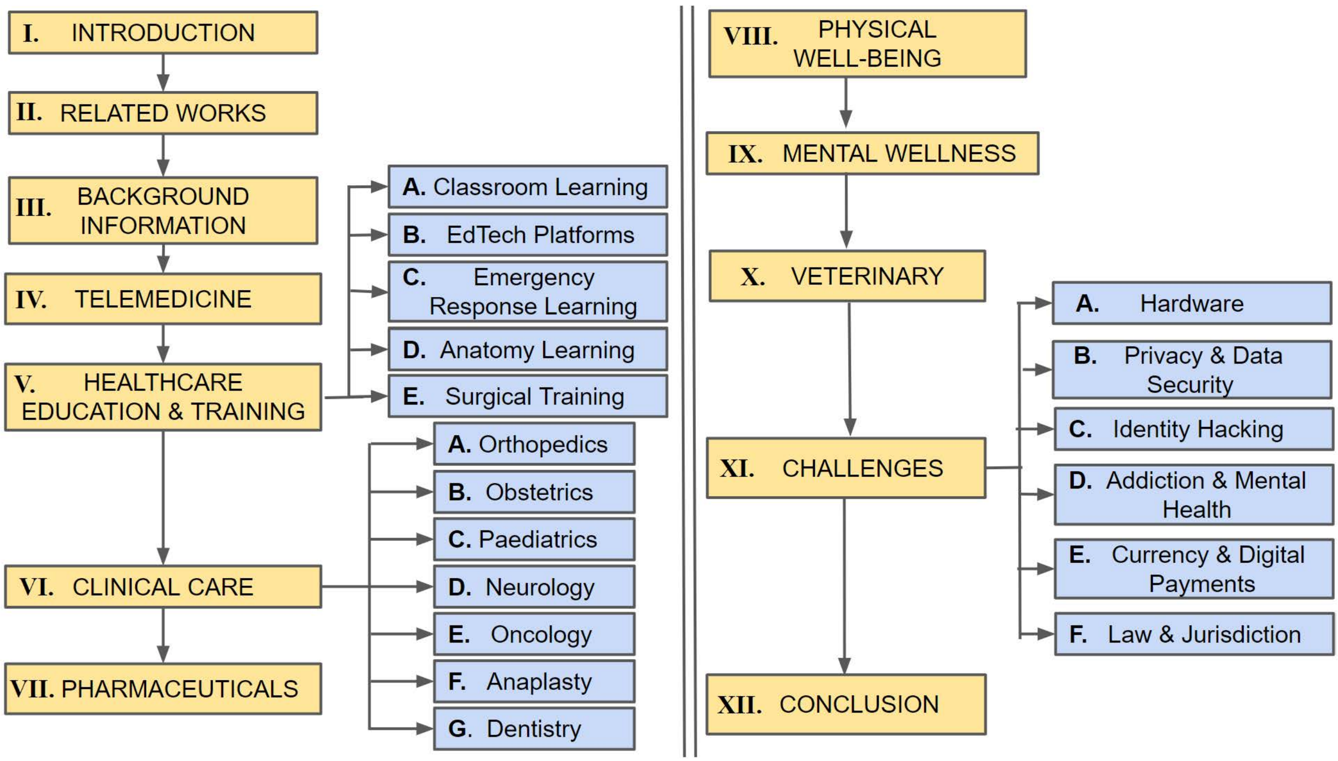

FIGURE 2. Overview of the survey.

domains of the healthcare industry, such as physical wellness, mental wellness, telemedicine, and veterinary. We also provide an in-depth analysis of how metaverse has been applied in the industry and what gaps need to fill before it can be accepted widely. Other works include [21] and [8]. Both of these surveys focused on the technological aspect of one of the applications in the healthcare domain. Quite comprehensive in their category, these works gave a fragmentary view of the metaverse in healthcare. The work [21] focuses on VR, AR, and IoT aspects of glasses that can be integrated with the technologies of holographic construction, holographic emulation, virtuality-reality integration, and virtuality-reality interconnection. Meanwhile, the work [8] focuses on what technologies metaverse is using and metaverse potentiality in medical healthcare. Both these works do not address the specifications particular to the healthcare industry. The survey [22] focuses on collaboration in virtual worlds and healthcare simulations. However, the work does not give an idea of how the metaverse applications assist in healthcare domains. We provide a more comprehensive analysis of formalized collaboration mechanisms, application standards, and future research avenues in healthcare by metaverse. Huynh et al., [17] in their survey published in 2022, discuss the role of AI in the metaverse and how it can revolutionize the current medical infrastructure. It includes a preliminary examination of AI, machine learning algorithms, and deep learning architectures, as well as their role in the metaverse, along with a comprehensive analysis of AI-based methods pertaining to six technical aspects with potential for the metaverse: natural language processing, machine vision, blockchain, networking, digital twin, and neural interface. The limitation of these works was that they focused on the particular technical aspects of the metaverse and not on the metaverse per se, as was the case in [21] and [8]. Instead of focusing on what is the impact of AI or blockchain in the metaverse-based healthcare industry, we discuss the industrial examples, applications, and forecasts of the metaverse. J.S. Lee et al. published a survey on AR/VR in the healthcare industry. Although the work does not comprehensively talk of metaverse application in the paper, it still provides integrated insights into how AR/VR can be applied to the metaverse. Compared to other approaches, our survey adopts a holistic view of metaverse applications, not just AR/VR. Finally, one of the most recent surveys was by Skalidis [23], which provided a survey on metaverse applications in cardiovascular medicine. The work has been quite consolidated and comprehensive but cardiovascular-specific. It can't be applied to other medical domains. There is a need for a more holistic approach that we address in our survey. Our survey adopts a comprehensive analysis of different domains healthcare industry and is not just limited to a particular domain. Table 1 summarises the comparison of various surveys to our survey.

To this end, this article analyzes the current technologies and technological infrastructures of a metaverse in the healthcare industry. Also, it provides a direction to researchers on

TABLE 1. Summary of different survey works.

Reference	Authors	Key focus of survey	How our survey differs
[20]	J. Thomason	Discusses metaverse applications in education, physical well-being, mental wellness, and clinical care domains of healthcare	Our survey cover other extended areas such as telemedicine, clinical care, and veterinary.
[8]	M. A. I. Mozumder et al.	Examines technology enablers of the metaverse, e.g., VR, AR, and IoT	Instead of focusing on what the emerging technologies are, we focus on how the enablers of the metaverse can be implemented in healthcare applications.
[21]	D. Yang et al.	Discusses how blockchain-based consensus can enrich applications in the metaverse	Instead of focusing on what the impact of blockchain in the metaverse-based healthcare industry is, we discuss the industrial examples, applications, and forecasts of the metaverse.
[22]	D. Holloway	Analyzes collaboration in virtual worlds and healthcare simulations	We provide a more comprehensive analysis of formalized collaboration mechanisms, application standards, and future research avenues in healthcare by metaverse.
[17]	T. Huynh-The et al.	Discusses how AI can aid in the development of the metaverse	We focus on the applications of the metaverse in healthcare rather than AI technologies that enable the metaverse itself.
[24]	J.S. Lee et al.	Examines the role of AR/VR in the healthcare industry	AR/VR are just ways to access the metaverse. Our survey adopts a holistic view of applications of AR/VR and the challenges it faces.
[23]	I. Skalidis et al.	Analyzes the role of the metaverse in cardiovascular medicine	Our survey adopts a comprehensive analysis of different domains healthcare industry and is not just limited to a particular domain.

how metaverse can help build seamless, shared, concurrent, and immersive virtual worlds for the healthcare industry.

III. BACKGROUND INFORMATION

A. TECHNOLOGIES

1) AUGMENTED REALITY

An Augmented Reality system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world [25]. An AR system should combine real and virtual objects in a real environment, runs interactively and in real-time, and aligns real and virtual objects with each other. AR can potentially span across multiple sensory modalities such as visual, auditory (sense of hearing), haptic (sense of touch), and olfactory (sense of smell). This experience is so thoroughly integrated with the physical world that it appears to be an immersive aspect of the physical environment. Augmented reality (AR) differs from virtual reality (VR), discussed below, in the sense that in AR, part of the surrounding environment is 'real' and adds layers of virtual objects to the real environment.

2) VIRTUAL REALITY

A Virtual Reality (VR) system is a fully immersive system with no world knowledge, in which the virtual world is rendered exquisitely, but the system does not consider the real environment [26]. Users can see the virtual world, move around, and interact with virtual features or objects while utilizing virtual reality technology. The impression can also be produced by specially built rooms with numerous large screens, although it is most frequently made by VR headsets that have a head-mounted display with a small screen in front of the eyes. VR headsets offer high-definition content with a broad field of view. To generate an immersive, realistic experience, input tracking is generally combined with a display that splits between the user's eyes, producing a stereoscopic 3D effect. Virtual reality typically includes audio and visual feedback, but haptic technology may also enable additional sensory and force feedback types. VR creates virtual environments by using sensory input. Users' actions influence the computer-generated environment, at least to some extent. In augmented reality, the real world is seen directly or through a device like a camera, and computer-generated inputs like still images, music, or video are added to that vision. In contrast to VR, augmented reality (AR) enhances the real-world experience rather than generating a brand-new one [27], [28].

3) MIXED REALITY

A Mixed Reality (MR) environment is one in which real-world and virtual world objects are presented together within a single display. MR is any display that jointly exhibits real and virtual objects for simultaneous perception. This may be accomplished in several ways. Using optical or video-see-through display technology, virtual things may be superimposed on the physical environment. Alternately, real-world material may be incorporated into a virtual environment by embedding a live video feed or, appealing to a different sense, by adding tracked haptic objects into a virtual experience [26], [29]. Mixed reality is a hybrid of augmented and virtual reality, taking place in both the actual and virtual worlds. Using advanced sensing and imaging technology, users can interact with and manipulate real-world and virtual objects, and surroundings in mixed reality [30], [31]. Without ever taking off the headset, mixed reality enables users to see and become fully immersed in the world around them while interacting with a virtual environment with one's hand. It allows users to have one foot (or hand) in the actual world and the other in an imaginary setting, bridging the gap between the real and the imaginary worlds and providing an experience that might alter how people work and play. Playing a virtual video game, grabbing a water bottle from the real world, and hitting a fictional character from the game with the bottle are all possible with mixed reality (MR) [32], [33].

4) EXTENDED REALITY

Extended Reality (XR) is a fusion of all the realities – including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) – which consists of technology-mediated experiences enabled via a broad spectrum of hardware and software, including sensory interfaces, applications, and infrastructures as defined by XR Safety Initiative (XRSI). XR is often referred to as immersive video content, enhanced media experiences, as well as interactive and multi-dimensional human experiences [34], [35]. According to Paul Milgram's theory of the reality-virtuality continuum, which encompasses the entire spectrum from "the complete real" to "the completely virtual," XR is a superset that contains everything in between. High-quality XR is getting easier to obtain. Customers are buying all-in-one (AIO) headsets (standalone headsets which do not require any external sensors) worldwide to experience XR, including immersive gaming, remote learning, and virtual training [36]. Large businesses are integrating XR into their design and workflow processes. With the addition of a digital twin, XR significantly enhances design implementation. And one of the significant developments right now is cloud-based XR streaming via 5G. This eliminates the requirement to be bound to workstations or to confine experiences to a specific setting. People can use XR devices and acquire the computing capacity to perform XR experiences from a data center, regardless of place or time, by streaming via 5G from the cloud. Immersive streaming is becoming more widely available thanks to cutting-edge technologies like NVIDIA CloudXR, enabling more XR users to experience high-fidelity settings everywhere [37], [38]. Recently, XR has been altering healthcare training by minimizing medical mistakes, increasing the skill of medical practitioners, lowering training expenses, and offering an immersive and interactive learning environment. Compared to standard training tools, immersive learning systems may significantly enhance training quality, save expenses, create chances for deeper knowledge, and increase patient satisfaction via improved treatment from healthcare professionals. XR facilitates the development of medical practitioners' competencies and the transfer of simulation-acquired skills to the operating room [39].

B. SOFTWARE AND HARDWARE FOR METAVERSE

1) MICROSOFT HOLOLENS 2

Microsoft HoloLens 2 is an untethered mixed reality headset (as shown in Figure 3) developed and manufactured by Microsoft. HoloLens 2 runs on the Windows Holographic OS, similar to Windows 10. HoloLens 2 is equipped with four visible light cameras for head tracking, two infrared cameras for eye tracking, a 1-MP Time-of-Flight depth sensor for depth measurement, an inertial measurement unit (IMU; comprises an accelerometer, gyroscope, magnetometer), and an 8 MP camera [40]. Instead of an Intel x86 processor, the HoloLens 2 employs a customized Qualcomm Snapdragon 850 processor. As a result, the headset will have longer battery life, better processing speed, and quicker wake-up times. A USB-C port, a Bluetooth connection that is more recent (5.0 vs. 4.1), and a new model of a holographic processing unit are all features of the HoloLens 2. A more potent RAM card (up to 8 GB vs. 2GB in HoloLens 1) and WiFi type (WiFi 5 vs. 802.11ac in HoloLens 1) are also different [41].

Version 2 of the HoloLens includes eye-tracking, which was not present in version 1. Eye-tracking sensors have been added to make interactions even more natural. In contrast, iris recognition technology allows users to log in without using passwords or other security measures. With the improved gesture tracking capabilities of the HoloLens 2, users can use gestures in mid-air to operate menus and other items on the displays. These involve actions like dropping goods off at a specific location or touching a virtual button on the wrist to display a menu. Now, the sensors can identify up to 25 points of articulation per hand through the wrist and fingers. They can determine the direction of palms, which indicates the ability to pick up objects in the simulated environment by bending fingers and moving hands. In contrast, the first HoloLens employed simple palm movements and gesture-based finger taps. With a field of view of 52° (compared to the HoloLens 1's 30°), the HoloLens 2 provides a more immersive MR experience for the user. Compared to the original HoloLens' 720p per eye resolution, the resolution has increased to a 2K display per eye. However, the density of the pictures has remained constant at 47 pixels per degree.

2) MICROSOFT DYNAMICS 365 REMOTE ASSIST

Dynamics 365 Remote Assist, a mixed-reality application developed by Microsoft, allows users to collaborate more efficiently by working together from different locations on HoloLens, HoloLens 2, Android, or iOS devices [44]. This application enables cross-device usage, sharing of videos and documents, video & audio communication, and smooth integration [45] with existing Microsoft applications, as shown in Figure 4. The on-site staff can give the remote experts the best possible explanation of the situation in the workplace by using Remote Assist and a HoloLens headset. With video

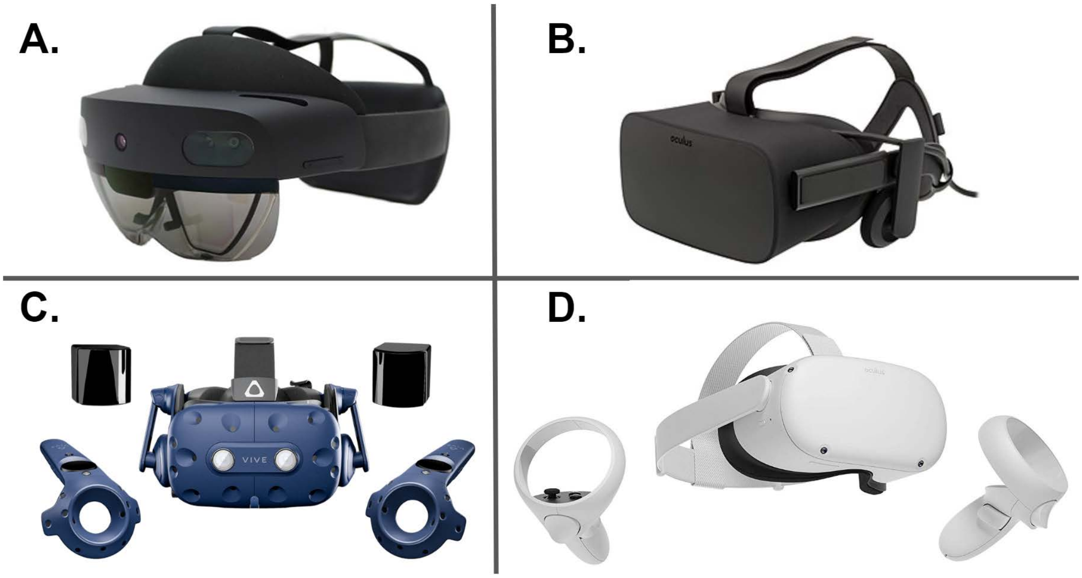

FIGURE 3. Popular VR Headsets: A. Microsoft HoloLens 2 [40]. B. Oculus Rift CV1 [42]. C. HTC Vive [43]. D. Oculus Quest 2 [42].

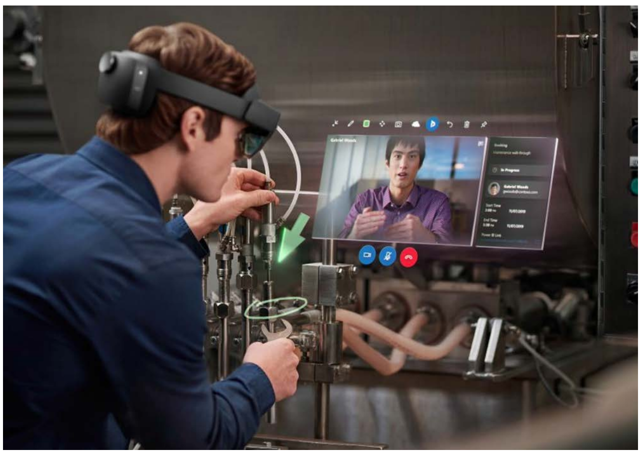

FIGURE 4. Dynamics 365 Remote Assist allows users to collaborate more efficiently by working together from different locations on HoloLens, HoloLens 2, Android, or iOS devices [44].

telephony, the remote expert can see via the data glasses or, in other words, can see on their screen what the employee can see in person. The expert can give the employee all the information needed during the live stream in their range of vision. This may include documents, movies, dashboards, circuit schematics, etc. The ''Live AR Drawing'' function also enables annotations that stick to the physical objects on-site to be drawn into the employee's field of vision.

3) OCULUS RIFT

Released on March 28, 2016, Oculus Rift is a discontinued brand of virtual reality headsets created and manufactured by Oculus VR, a branch of Meta Platforms [42]. Using the Oculus PC SDK, a free proprietary SDK available for Microsoft Windows, content for the Rift is developed (OSX and Linux support is planned for the future). This fully-featured SDK handles the many components of creating virtual reality content for the developer, such as optical distortion and advanced rendering techniques. Oculus Rift CV1 (as shown in Figure 3) and Oculus Rift S were the two VR headsets released under the Rift brand.

The prominent game engines Unity 5, Unreal Engine 4, and Cryengine are fully integrated with the Oculus SDK. This enables developers used to these engines to produce VR content with minimal VR-specific code.

The Rift is an open platform; hence, developers do not require approval or verification to create, distribute, or sell content for it, nor are they required to pay license costs. However, the SDK cannot be updated or reused for other applications or devices without permission.

4) HTC VIVE

VIVE, often known as HTC Vive, is a virtual reality brand owned by HTC Corporation [43]. It consists of hardware such as VR headsets (as shown in Figure 3), accessories, virtual reality software and services, and programs that promote the use of virtual reality in industries such as business and the arts.

The HTC Vive uses ''room-scale'' virtual reality, allowing users to move freely around a play space instead of being confined to a stationary position. The controllers and headset use a positional tracking technology referred to as ''Lighthouse''; multiple external base station units (also known as ''lighthouses'') are mounted in the play area, each containing an array of LED lights and two infrared lasers. The lasers are coupled to rotating spinners that sweep the play area with timed pulses vertically and horizontally. The headgear and controllers incorporate photosensors that detect the LED lights from the base stations and compare them to the timing of the laser sweeps to establish their relative position in three-dimensional space.

The Vive comes with two wand-like motion controllers and has circular trackpads similar to the Steam Controller. The headset features two OLED display screens with a resolution of 1080 × 1200 per eye, a refresh rate of 90 Hz, and a field of view of 110 degrees. It includes an accelerometer, gyroscope, and proximity sensor, as well as a front-facing camera used for the ''Chaperone'' feature, which can display the borders of the user's chosen perimeter or the view of the camera to steer the user away from objects and walls in their play area.

The Vive initially required Microsoft Windows-based computers. In February 2017, Linux support was added, followed by macOS support in June 2017. Valve removed macOS support for SteamVR in 2020, citing their intention to focus entirely on Linux and Windows in the future.

5) OCULUS QUEST 2

Oculus Quest is a standalone VR headset (Figure 3), i.e., it can operate inside the virtual environment freely without getting tangled up in a cable in the real world [42]. It uses a dual OLED model with a definition of 1440 × 1600 pixels per eye and a refresh rate of 72Hz. Oculus' Guardian system prevents users from banging into their physical surroundings, such as walls and furniture. There are four cameras (one on each corner of the headset) to track and map the space around the user, ensuring the user will not collide with any obstacles near them. Quest runs on the Oculus OS, a variation of Android, and includes tracking technology called Oculus Insight (no external sensors), as in the case of Oculus Rift S. It runs on a Qualcomm Snapdragon 835 mobile processor. Since Quest uses its own operating system and processor, there is a limit to its graphic and rendering capabilities. Compared to Oculus Quest, Oculus Quest 2 is equipped with 1832 × 1920 pixels per eye, Qualcomm Snapdragon XR2, and 6 GB RAM [46].

6) SENSEGRAPHICS H3D

SenseGraphics H3D is a commercial software development platform licensed under the GPL (open source) for multi-sensory applications [47]. H3D API utilizes the open standards X3D and OpenGL and the haptic technology from the SensAble OpenHaptics toolkit [48]. OpenHaptics toolkit supports haptic devices developed by 3D Systems such as Touch 3D stylus device, Touch × haptic device (as shown in Figure 5), and Phantom Premium haptic devices. With a high-level scripting interface and the X3D standard format for web-based 3D, haptics programming has become simpler.

7) UNITY ENGINE

Unity is a cross-platform game engine [49] created by Unity Technologies; it was first unveiled and launched as a Mac OS × game engine at the Apple Worldwide Developers Conference in June 2005. Since then, the engine has been expanded to accommodate several desktops, mobile, console, and virtual reality platforms. It is prevalent for iOS and Android mobile game development, is considered straightforward for new developers, and is famous for indie game creation. Unity allows users to build games and experiences in both 2D and 3D, and the engine offers a powerful scripting API in C# using Mono for both the Unity editor in the form of plugins and games themselves, as well as drag and drops capability, as shown in Figure 6. Before C# being the primary programming language used for the engine, it initially supported Boo, which was discontinued after the release of Unity 5, and a Boo-based implementation of JavaScript called UnityScript, which was deprecated in August 2017 after the release of Unity 2017.

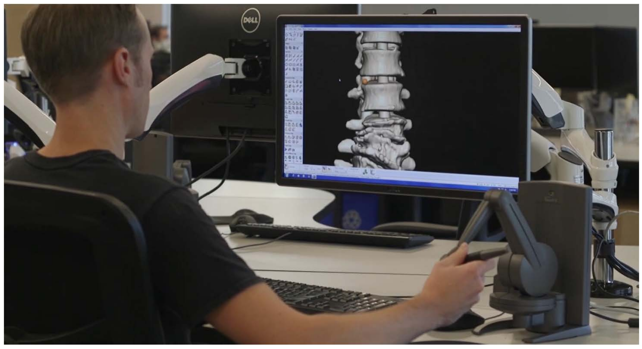

FIGURE 5. OpenHaptics toolkit supports Touch × haptic device and is an essential tool to develop haptics and 3D navigation for pre-surgical planning and patient-specific models [47].

Unity allows for the importation of sprites and a powerful 2D environment renderer within 2D games. Unity enables bump mapping, reflection mapping, parallax mapping, screen space ambient occlusion (SSAO), dynamic shadows using shadow maps, render-to-texture, and full-screen post-processing effects for 3D game development.

In addition to the built-in legacy pipeline, two different render pipelines are available: High Definition Render Pipeline (HDRP) and Universal Render Pipeline (URP). Each rendering pipeline is incompatible with the other two. Unity provides a tool for upgrading outdated renderer shaders to URP or HDRP.

8) HAPTICMASTER

The HapticMaster [50] is a commercial device developed by Moog FCS Robotics [51]. It was acquired for the H-Haptics program and utilized in other research (e.g., by Tricia Gibo and Jack Schorsch). This software makes it simple to manipulate virtual dynamics, forces, and perturbations in a SIMULINK environment.

Because it is an admittance (force-controlled) device, it can deliver high stiffnesses and forces with low friction. It supports position resolution of 4 × 10-6 to 12 × 10-6 m (depending on position), maximum stiffness of 10 × 103 to 50 × 103 N/m (depending on position), and nominal/maximum force of 100-250 N. As it is an admittance-controlled device,

FIGURE 6. Unity engine serves as a 3D development platform for AR and VR applications [49].

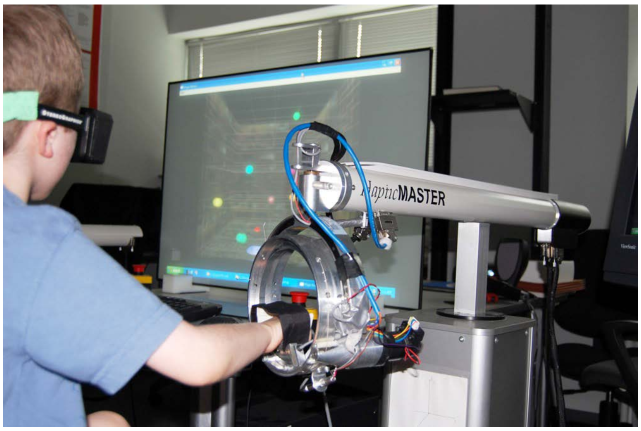

FIGURE 7. The New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation system for children with cerebral palsy is interfaced with the HapticMaster using a ring gimbal [52].

the end effector contains a force sensor, which can be utilized to quantify human-machine interaction forces.

9) ARTOOLKIT

ARToolKit [53] is a C and C++ software library that facilitates the development of Augmented Reality applications by programmers. Augmented Reality (AR) is the superimposition of computer-generated graphics onto the real world, and it has numerous potential uses in industry and academic research. One of the most challenging aspects of designing an Augmented Reality application is accurately estimating the user's viewpoint in real-time so that virtual graphics perfectly align with actual world surroundings. ARToolKit utilizes computer vision techniques to calculate the precise camera location and orientation with marked cards, enabling the programmer to superimpose virtual items onto these cards. ARToolKit is presently compatible with SGI IRIX, PC Linux, Mac OS X, and PC Windows (95/98/NT/2000/XP). The most recent version of ARToolKit is fully cross-platform. The functionality of each version of the toolkit is identical; however, hardware configurations may affect performance differently.

ARToolKit's current version supports both video and optical see-through augmented reality. Virtual visuals are superimposed on live footage of the physical world in video see-through augmented reality. The alternative is optical see-through augmented reality, which overlays computer visuals directly on a view of the actual world.

C. THE RISE OF METAVERSE

The most prominent advantage of the metaverse would be that it eliminates geographical limitations. As soon as one enters the virtual world, the user's actual location becomes irrelevant, and one is no longer constrained by it. The metaverse will function as a neutral area where all parties may meet on an equal footing. Additionally, discovering and meeting others with similar interests and opinions will be simpler and help you feel more at ease making new friends from the comfort of their homes. Metaverse may be considered a 3D enhancement to the conventional internet use model. It is a more immersive approach to experiencing the many facets of the Internet and all it has to offer. The metaverse has had both a social and economic impact. Almost 60% of users are enthusiastic about incorporating technology into their daily lives, with the closeness between individuals being the primary motivator, followed by the opportunity to explore digital worlds. 95% of business executives anticipate that the metaverse will have a favorable influence on their sector during the next five to ten years, and 61% anticipate that it will have a moderate impact on how their company works.

In contrast, the economic effect of the metaverse's potential economic value might reach $5 trillion by 2030, similar to the size of the world's third-largest economy today. It is shaping to be the most significant new development potential for several sectors over the next decade. It might affect the global GDP by 2.8% by 2031. A substantial benefit of the metaverse is that one gets more immersed in their task; thus, it opens up additional possibilities for personal and professional endeavors. The combination of the capacity to construct virtual places in the metaverse with the potential of social media to create shared online worlds is a highly potent combination that will allow us to experience social media in unprecedented ways. The metaverse will make learning more accessible than ever before. No longer must the actual location of the classroom be taken into account. In a hands-on educational environment, people from across the globe can exchange knowledge and learn together in real time. In addition, because we have complete control over what pupils see inside the metaverse, visual learning will facilitate the communication of ideas and concepts. The students would be able to see historical occurrences firsthand instead of theoretically studying them [54], [55].

IV. TELEMEDICINE

The healthcare industry necessitates constant human contact with the patient to detect both physical and emotional responses. However, the pandemic has disrupted this process, and thus there is a search for the adoption of remote care

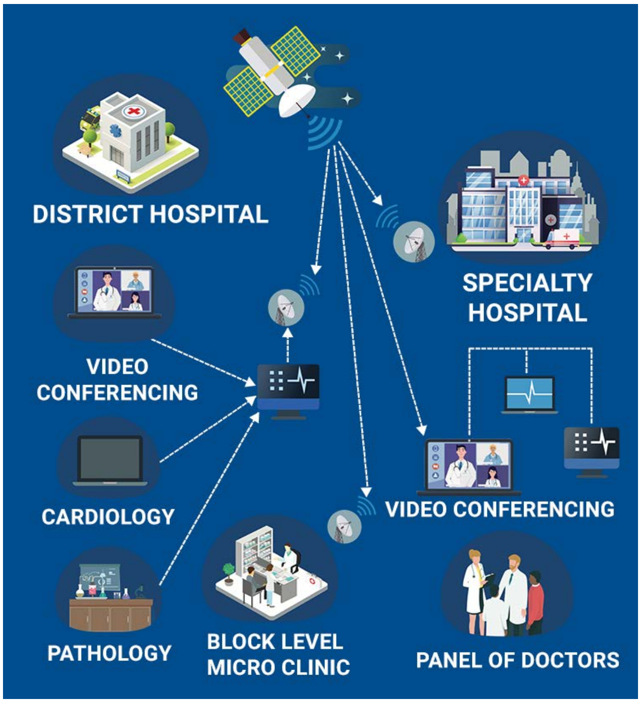

FIGURE 8. Telemedicine case study application in India [60].

FIGURE 9. Zimmer Biomet's OptiVu Surgical app will let surgeons and patients visualize a procedure together [61].

technologies such as telehealth, which uses digital information and communication technologies to obtain health care services from a distance. According to [56], before the COVID-19 pandemic, only 43 percent of healthcare facilities in the United States could provide telehealth, but by 2020, that number had risen to 95 percent [57]. Telemedicine is a general term that covers communication between patient and doctor using technology without being in the same room. It consists of telephone conversations, video chats, emails, and text messaging. Telemedicine is also known as digital medicine, telehealth, e-health, and m-health [58].

Metaverse will be able to supplement these visits with a virtual office, allowing patients and clinicians to meet in a 3D clinic or anywhere else it is conducted [59]. A case scenario is presented in Figure 8 of India, where metaverse can help connect patients from rural areas to get medical facilities at the touch of a hand [60]. A patient can go to a nearby clinic, where he has been diagnosed with diseases like "eczema". The cure for such a condition is not available at the clinic. Using metaverse, consulting doctors can take opinions and suggestions of different panel doctors sitting across the globe in district hospitals and multi-specialty hospitals via video conferencing. This would help the patient get medical attention very quickly. Secondly, it would decrease the improved communication among the doctors and better consultation. Thirdly, the need for large multi-specialty hospitals at every nook and corner can be minimized. Some metaverse case studies in telehealth/telemedicine/teleconsultation are as follows:

1) The Epazz Slims [62], created by Epazz Inc., will enhance virtual telemedicine between doctors and patients by creating an actual 3D depiction of a person. The Epazz Slims are virtual reality glasses equipped with several nano cameras and motion sensors that assist in creating an actual 3D depiction of a person. The metaverse technology will let patients and clinicians meet virtually and communicate in real time throughout the clinical examination, with full sensory engagement. In augmented reality, the patient will feel touch and general movement. It will allow the patient to convey a 3D graphic of the afflicted body part to the doctor. The embedded cameras of the Epazz Slim will generate the patient's 3D avatar, allowing for real-time interactions and conversations.
2) Zimmer Biomet, a medical device company, has announced OptiVu software [61] that provides holographic visualizations to doctors and patients. It employs Microsoft HoloLens to blend the physical and digital worlds, as seen in Figure 9. The working of Hololens has been explained in section III. Through data interconnection, patients will be able to replicate realistic consultations, personalized care, treatment, and diagnosis.

Thus, the metaverse can transform the healthcare industry by bridging the gap between the patient and the doctor. Some of the advantages that can be achieved by metaverse in the telemedicine domain are:

- Many people find it unsettling to visit a hospital or physician's office. Metaverse facilitates communication between patients and healthcare professionals while retaining patient convenience. In addition, with telemedicine, medical information and reports are sent securely from one location to another. Thus, individuals may have confidence in this system and seek its assistance with confidence.
- Rural areas, distant locations, and post-disaster scenarios face issues due to unreliable healthcare structures present at these locations [63]. Metaverse in telemedicine may be used in such places or circumstances to deliver emergency healthcare. Without an arduous journey to the hospital, patients may obtain clinical treatment at home.

- Modern information technology advancements, such as mobile collaboration, have facilitated the sharing and discussion of vital medical case information among healthcare practitioners in many locations.
- Since telemedicine has allowed patient monitoring using a computer, tablet, and phone technologies, reducing the cost of healthcare. Now, physicians can confirm prescriptions and oversee medication supervision.
- Telemedicine reduces the risk of infectious disease transmission between patients and medical personnel.

V. HEALTHCARE EDUCATION AND TRAINING

It is anticipated that 2D books and non-interactive surroundings will give way to 3D and interactive teaching at virtual universities powered by the metaverse, replacing the traditional education system. This enables individuals in faraway locations to study in a 3D virtual environment and engage with other students, regardless of their geographic, political, or health restrictions. After the introduction of Covid-19 and the ensuing constraints, the flaws of the modern schooling systems were evident to everyone. Covid-19 limitations on the present virtual education system have several detrimental effects, including a decline in the quality of education and a decrease in students' enthusiasm to study. The artificial intelligence, augmented reality, and virtual reality technologies used in the metaverse have made it a suitable platform for developing and improving existing educational systems. By engaging in 3D settings enabled by metaverse technology, students can acquire a realistic experience of real-world learning situations without location, time, or money constraints.

The technology of virtual reality enables students to access the human body, giving them a thorough picture and allowing them to replicate real-life medical procedures. Additionally, augmented reality (AR) is being utilized to promote hands-on learning opportunities for students, such as mimicking surgical and patient interactions and enabling medical students to envisage and practice novel procedures (Figure 12).

This section discusses the applications of a metaverse in healthcare education. For better understanding and readability, we break healthcare education into five categories: classroom teaching, EdTech platforms, emergency response training, anatomy learning, and surgical training. In the following sub-sections, the paper describes the applications of the metaverse in each of the subdomains in detail.

FIGURE 10. Nursing Facility at University of Northampton assisting in classroom learning [64].

FIGURE 11. Virtual window into pregnancy offered by the University of Newcastle, Australia [65].

A. CLASSROOM LEARNING

The COVID-19 pandemic has hampered nursing students' ability to hone skills such as clinical care, interpersonal relationships, and emergency response training. So some researchers have been working on an e-classroom learning paradigm using metaverse. Some of the use cases are:

1) The University of Northampton has constructed a VR simulation suite for nursing students. The projection screen, as shown in Figure 10 enables group instruction by projecting what the learner sees in VR onto the screen [64].
2) At the University of Newcastle, Australia, midwifery students are provided with a world-first window into the intricacies of pregnancy to gain a better understanding of common issues such as breach positioning, and placenta placement [65]. The team developed a VR technology to follow a comprehensive, realistic, three-dimensional figure during pregnancy without encountering any visual constraints, as shown in Figure 11. It is the first system to employ VR and MR technology to illustrate all phases of birth. It has been created

FIGURE 12. a) Virtual reality headset worn by a nursing student. b) A cardiac assessment is being conducted on a fictitious patient. b) Using multiple displays to project an immersive experience using VR for group learning. d) Responses of a simulated patient's pupils to light [64].

for various platforms, including HTC Vive, Microsoft HoloLens, PC, Mac, Android, and iOS. Users can navigate from week 1 to week 42 via a user-controlled virtual scrollbar on a tablet, a hand controller in VR, or hand gestures in VR. In addition, the fetus, placenta, and the subject's (mother's) internal organs will develop differently in the virtual environment seen by the user. There are two user experiences for visualizing instructional content, an MR experience and a VR experience. This use of VR can be potentially used in the classroom or in the student's own time and will be able to benefit regional, and remote practitioners, as well as expectant parents [66], [67].

3) The MOOG Simodont VR haptic dental simulator [68], [69] is being used to teach the students regarding dental training. The simulator delivers realistic haptic force feedback based on the admittance control paradigm of the HapticMaster [50], a commercial 3 DoF haptic device [51] manufactured by Moog FCS Robotics. The simulator reacts to the force applied by a user, giving the impression that the user is engaging with an item of equivalent mass. When the user puts on the stereoscopic glasses, the Simodont Dental Trainer's computer screen displays high-resolution teeth and dental equipment visuals with 3D projection. Underneath the display is a physical handpiece with a virtual tip that may be utilized to execute tooth preparation treatments accompanied by realistic sound reproduction. In the device used, the speed of the virtual handpiece could be adjusted using a physical foot pedal. The simulator is supported by software from Courseware. This application records the real-time kinematics of student performance and includes a variety of manual dexterity exercises and operational dental procedures with varying degrees of difficulty. Manual dexterity activities from the Courseware software were used to teach and assess all participants in the preparation of fundamental abstract forms using similar dental equipment

(high-speed handpiece and one type of dental burs-FG 856/016 [70]). When inexperienced participants were given haptic device input with a professional dentistry teacher, learning basic manual dexterity abilities was expedited compared to those who only had access to the device or instructor-alone feedback.

4) Individual Dental Education Assistant (IDEA) simulator [71], a hand dexterity using haptic VR technology simulator, was used to teach students who may encounter academic difficulties in the pre-clinical phases of dental school. The technology comprises a portable stylus haptic device replicating a dental handpiece with force feedback and simulation software that can be loaded on regular PCs. The student operator handles the haptic stylus instrument while seeing the simulation on a standard 2D computer monitor. The multi-client system utilized has a central server managed by an administrator. This module defines manual dexterity as the user's ability to accomplish tasks requiring hand-eye coordination. The VR testing setup comprises a surface with various material-coated routes that the user must remove using the manual dexterity module of the haptic simulator. The simulator monitors the carving distance from the route, the time passed since the start of the test, the carving depth, the percentage of the removed area, the haptic force, and the location of the handpiece to determine the degree of accuracy.
5) At a dentistry school in Brazil [72], teachers constructed a novel learning platform using augmented reality technology in teaching virtual teeth preliminary design. These virtual teeth are created using the ColorMapEditor (CME) application based on the SenseGraphics H3D toolkit [47]. CME is a software tool developed to modify and color a cone-beam computer tomography (CBCT) scanned image of a tooth [73]. Using a virtual tooth model, which may be more analogous to the clinical setting than plastic teeth, enables students to combine learning based on their skill and competency by allowing them to make clinically-relevant judgments during their training.

Thus, the metaverse can bring online learning environments to life. Educators are able to design classrooms to meet their specific demands and help teachers dynamically change the environment for training the students. In the following subsection, we discuss the other subdomain of learning: the EdTech platforms. EdTech is the implementation of IT tools in the classroom to create a more engaging, inclusive, and individualized learning experience. They are quite closely knitted with classroom learning, but we categorize it as a separate domain for better understanding.

B. EDTECH PLATFORMS

EdTech is the educational technology that combines computer hardware, software, and educational theory and practice to support learning. Some metaverse applications that are transforming the traditional EdTech platforms are as follows:

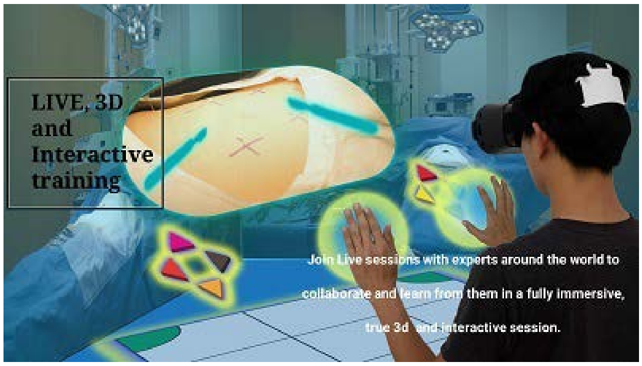

FIGURE 13. Health training in metaverse [74].

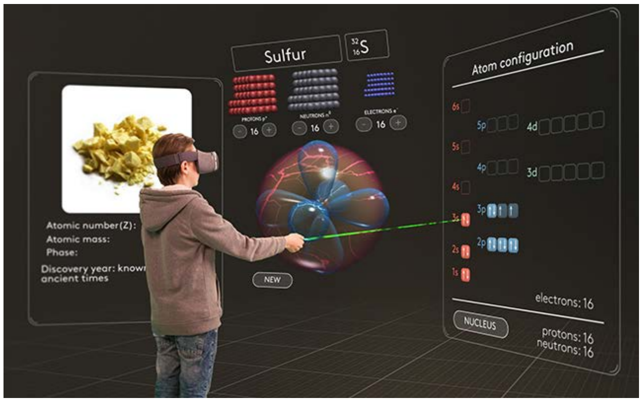

FIGURE 14. Virtual reality lessons in MEL VR app [75].

1) Studyum [76], an EdTech platform that provides venues for the organization of collaborative activities for learning or training students. It uses a reward mechanism to incentive intra-community collaboration. For every class attended, video viewed, and assignment submitted, users are rewarded with tokens. Thus, it provides different education/training resources for learning based on training and performance. A trainer could be a "celebrity surgeon," with the surgeon being compensated for his instruction and the students receiving recognition for their progress via rewards.
2) Global Healthcare Academy (GHA) intends to bring medical education and healthcare to the metaverse in collaboration with 8chili [77], a California-based software startup, by developing an EdTech platform (Figure 13). The partnership has already published more than 200 hours of virtual reality (VR) content in various sub-specialties, including dentistry, oral and maxillofacial surgery, skull base, orthopedics, neurology, spine, ENT, paramedics, oncology, and nursing [74]. VR-based imitation learning will address the lack of hands-on training for skill acquisition by allowing residents to relive the surgery and learn by

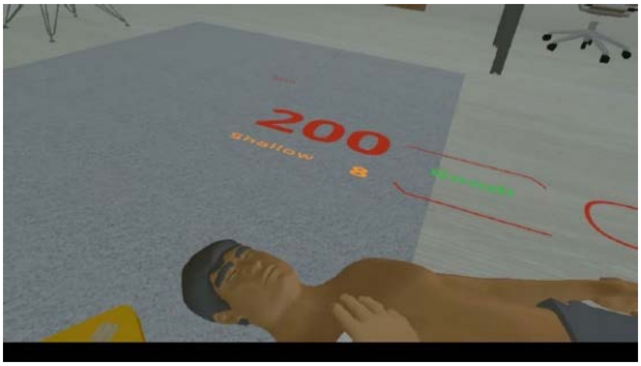

FIGURE 15. 3D representation of a realistic human victim on the mannequin for training in a VR environment [78].

emulating the surgeon's actions with virtual tools and haptic input. The 8chili HintVR platform makes it quick and straightforward to create 3D immersive content, eliminating the content problem and aiding business enterprises in introducing the metaverse.

3) MEL Science, located in London, has introduced a virtual reality lecture series on the EdTech platform aimed at students in grades K-12 [75]. The company launched the MEL VR app, incorporating a virtual chemistry lab to enliven and demonstrate molecular-level science on an immersive, expanded scale. Students will have the option to use their hands or a guiding instrument to construct an atom of any known element, as illustrated in Figure 14. Students should be able to study fundamental chemical principles in an engaging, welcoming manner, including the distinction between solids and gases, the structure of an atom, what an electron orbital is, and what an isotope is.

Having discussed the applications of the metaverse in the classroom environment, it is also essential to understand how it would impact medical trainees in case of emergency.

C. EMERGENCY RESPONSE LEARNING

Everything can't be taught simply by books. It is essential for medical trainees to have hands-on experience on how to respond to an emergency and help the patient. Just like there is a first aid kit to help the person till the ambulance arrives, there are many emergency response training that can act as life-saving techniques and the cornerstone of resuscitation [80]. The trend of the metaverse in emergency medicine education, especially resuscitation, will progress further because of its applicability in teamwork learning, decision-making, and high-stress immersion resuscitation experience. Using metaverse, healthcare specialists can focus on training for optimized decision-making and action-taking during mass casualty incidents [12]. Some of the applications of the metaverse in emergency response learning are:

1) A Cardiopulmonary resuscitation system is developed by [78], which allows students to learn skills such as rescue breathing, chest compressions, and using an automated external defibrillator (AED) using VR (Figure 15). It allows tutorials, demonstrations, and computer-generated interactive scenarios in conjunction with hands-on training, using HTC VIVE and Unity3D as the VR system and software development, respectively. For precise measurements of chest compressions such as rate, depth, recoil, the position of hands, and AED, a tracking system is constructed utilizing virtual planes and VIVE-Tracker. For accurate haptic feedback and hands-on training, a life-like mannequin is introduced into the VR environment and superimposed with a virtual 3D human model. The VIVE-controller provides precise synchronization between the mannequin position in the real world and the virtual model in the virtual space.

2) The Gordon Center for Simulation and Innovation in Medical Education, a University of Miami Center of Excellence, have recently begun to use emergency management training in AR, VR, and MR platforms to train healthcare staff to prepare them better to respond to situations that require immediate attention, such as stroke, heart attack, and irregular heartbeat [81]. Harvey, the Gordon Center's most enduring example of innovative healthcare simulation work, is a cardiopulmonary patient simulator. Harvey was created in 1968 and is used to simulate any cardiac disease, including blood pressure, pulses, breathing, heart sounds, murmurs, and lung disease, in a virtual environment.

A.

B.

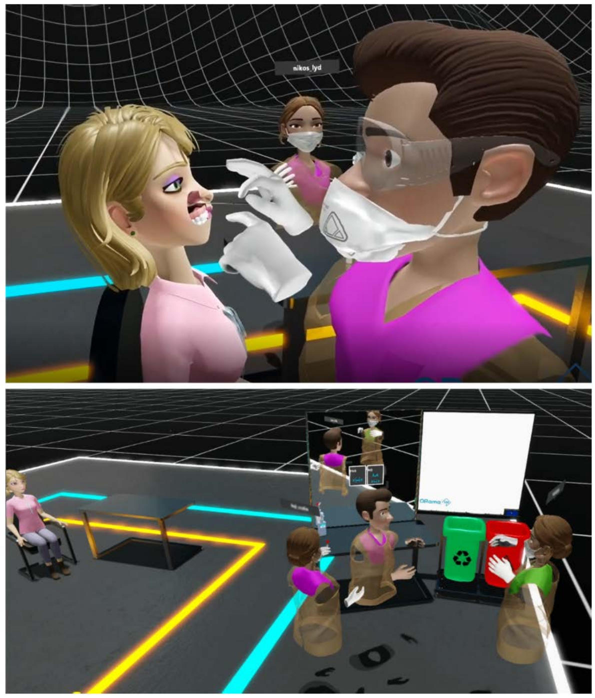

FIGURE 16. A. The instructor demonstrates how to perform a nasopharyngeal swab test. B. Instructor demonstrates proper disposal of PPE kits in a virtual classroom in CVRSB platform [79].

3) VR simulations are being used as an effective tool in the Department of Emergency Medicine, Inselspital, University Hospital Bern, Switzerland, to teach medical students about COVID-19 clinical diagnostics [82]. The students are trained in COVID-19-related skills using COVID-19 VR Strikes Back (CVRSB) module, a VR medical training application developed by ORamaVR SA, and the Oculus Rift S headset and hand controllers [79], [83]. CVRSB software module offers a faster and more efficient teaching experience for medical personnel regarding the nasopharyngeal swab and the proper Personal Protective Equipment (PPE) donning and doffing, as shown in Figure 16. MAGES, a VR-based authoring SDK for accelerated surgical training and assessment, is utilized as the basis for the CVRSB application development. A built-in reflective mirror facilitates immersion in the event of PPE donning and doffing. The software supports all SteamVR-enabled Desktop HMDs and the untethered, mobile HMDs.

In the following subsection, we discuss specific applications of metaverse for physiologists and anatomists. A human anatomist is a medical and biological specialist who focuses on the morphology of the human body and its components while studying the human body. For medical physicians (or other medical professionals) to investigate illnesses, they must understand the structure and function of the body. Consequently, anatomy is crucial in comprehending how the body functions regularly and incorrectly (diseases).

D. ANATOMY LEARNING

Human anatomy is the study of the human body's structures. Anatomy knowledge is essential for the practice of medicine and other fields of health. Word "anatomy" is derived from the Greek terms "ana," which means "up," and "tome," which means "a cutting." Traditionally, anatomy studies have entailed the dissection of organisms. For any medical practitioner, it is crucial to learn anatomy. It is impossible to learn how to repair anything without understanding its structure; the same applies to medicine. Anatomy is essential to comprehend how the body functions normally and abnormally (diseases). Some metaverse applications that can help teach/learn anatomy are:

1) Project Polaris [86] is a three-dimensional holographic system developed by the National University of Singapore (NUS) Yong Loo Lin School of Medicine in collaboration with Microsoft and the National University Health System. The project teaches medical procedures and examines anatomical features. Undergraduate medical and nursing students may expect to enhance their abilities via Project Polaris training, which employs the Microsoft HoloLens 2 to offer them a visual awareness of real-world clinical settings such as cannula and catheter placement in male and female urinary tracts.
2) Elsevier, a global educational publisher, and GigXR, a developer of XR solutions for instructor-led teaching and training and provider of the 3D for Medical human anatomy platform, have developed HoloHuman (shown in Figure 17). This mixed reality anatomy application allows instructors to provide students with holographic learning environments. HoloHuman enables simultaneous in-class and remote participation utilizing Microsoft HoloLens headgear and mobile devices compatible with Android and iOS, all of which access the same views inside a shared session. All local and remote players may interact through the program during an active HoloHuman session with VoIP capabilities. HoloHuman enhances clinical preparation for real-life diagnostic, research, and hospital settings by providing a better understanding of human anatomy. This application provides users with specific information about each body part in a 3D holographic view, as well as parts of the human body such as the thorax, 11 distinct systems such as the respiratory or cardiovascular systems, and simultaneous views of multiple anatomical systems with the ability to overlay any combination of them. Instructors may configure how models look and text presented as labels, and models can be stored to open during a lesson later. This software's remote features and support for mobile devices allow it to handle bigger classrooms without compromising teaching efficacy, according to [84].
3) Western Reserve University in Cleveland, Ohio, produced HoloAnatomy [85], an all-remote anatomy course in mixed-reality software on the Microsoft HoloLens devices. Students could study on their schedules and have more excellent physical room to walk around the anatomical models. Students were equipped with their own Microsoft HoloLens mixed-reality devices with the digital anatomy curriculum HoloAnatomy software installed during remote classes, as shown in Figure 18. The HoloAnatomy Software Suite consists of the Designer Tool, the Anatomical Hologram Library, the Viewer App, and the HoloAnatomy Network. The Designer Tool is identical to PowerPoint in principle and is installed on the PC of the course instructor. This enables instructors to create personalized presentations utilizing the anatomical art collection. The material may then be effortlessly distributed to several HoloLens headsets. It is possible to apply automatic or custom labels, highlight characteristics, change body locations and sizes, and make male and female anatomy comparisons. Once a 3D "slideshow" has been built, course instructors click a "publish" button, and students may begin exploring the information in class immediately. Anatomical Hologram Library is a collection of digital 3D anatomy art materials with pictures of male and female models reflecting the anatomy of a typical healthy middle-aged adult. The Viewer App is a HoloLens app that displays

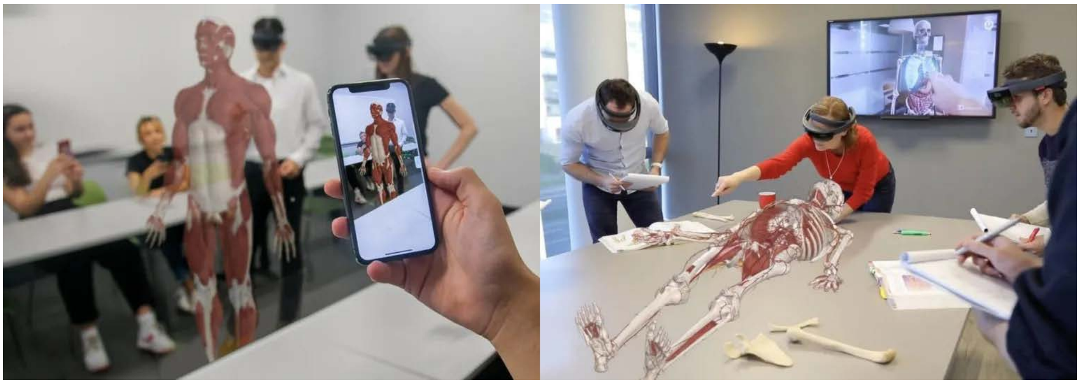

FIGURE 17. HoloHuman being used to generate 3D holographic learning environments [84].

FIGURE 18. A. HoloAnatomy is being used to generate holographic images of different body systems. B. Brain study being performed using HoloAnatomy. C. Detailed anatomy of the heart is visualized using Microsoft HoloLens [85].

holographic material generated using the Designer Tool. Using standard classroom Wi-Fi, a networking architecture allows multi-user classroom interactions for large and small groups [87]. As shown in Figure 18, Holoanatomy is used to evaluate and research different bodily systems, such as circulatory, respiratory, and so on, as well as particular body sections like the brain and heart.

Surgical postgraduate training is one of the most extensive training programs in the medical sector. The majority of surgical training programs need five to six years of postgraduate education to qualify. Typically, this is followed by one to two years of fellowship study in a subspecialty. Over the last 20–30 years, there has been no significant change in this situation. The rapid transformation of surgical practice is attributable to developments in medical technology. Next, we show how metaverse applications can help transform these surgical training.

E. SURGICAL TRAINING

Surgical training includes procuring the knowledge and skill set necessary for a physician to perform safe and therapeutically effective patient operations. The objective of surgical training is to prepare physicians for surgical specialization. With the rise of the metaverse, surgical simulators have been developed for training students in surgery. Surgical simulators enable the planning and preparation of complicated operations and the generation of structured data for algorithm

TABLE 2. Study of different metaverse in healthcare education.

Work	Category	Area	Location	Augmented Reality	Virtual Reality	Simulations
[64], [88]	Classroom learning	General	University of Northampton	No	Yes	Yes
			John Radcliffe Hospital, Oxford	No	Yes	Yes
[65], [66], [67]		Pregnancy	University of Newcastle, Australia	No	Yes	Yes
[68], [69]		Dental	-	No	Yes	Yes
[71]			-	No	Yes	Yes
[72], [73]			Brazil	Yes	No	No
[76]	EdTech Platforms	Gamified Learning	-	Yes	No	No
[74], [77]		Medical education	California	No	Yes	Yes
[75]		Chemistry lectures	MEL Science, London	Yes	No	No
[80]	Emergency response learning	Cardiopulmonary	-	No	Yes	Yes
[78]		Chest compressions	-	No	Yes	Yes
[81]		Heart attack, Stroke	University of Miami	Yes	Yes	Yes
[85]	Anatomy learning	Anatomy	Western Reserve University, Ohio	Yes	Yes	Yes
[84]			Microsoft	Yes	Yes	Yes
[86]			NUS , Singapore	Yes	Yes	Yes
[89]	Surgical training	Digital surgery	Medtronic, London	No	Yes	Yes
[90]		Submandibular gland	-	Yes	Yes	Yes
[91]		Dental anesthetic	-	No	Yes	Yes
[92]		Maxillofacial surgery	-	Yes	Yes	Yes

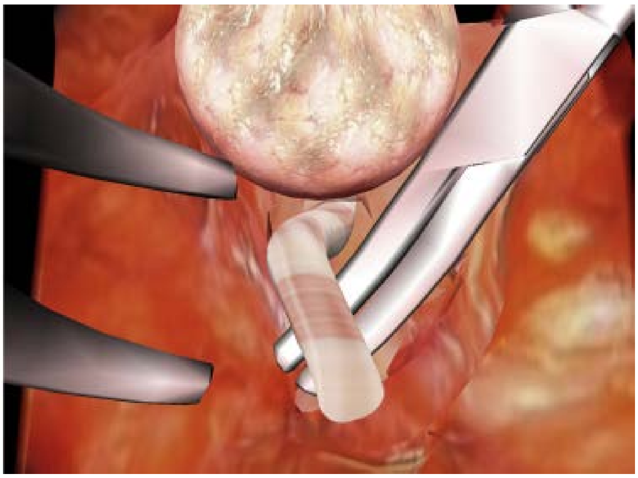

FIGURE 19. VR image of the exfoliation of the submandibular gland and vessel under the layers of connective tissue using two pean forceps [90].

development, which may be used in image-guided computer-assisted treatments such as:

1) Digital Surgery is home to the Touch Surgery platform [89], an immersive surgical VR simulator for healthcare practitioners. Digital surgery offers an AI-powered surgical video management platform and in-OR digital solutions for hospitals.
2) Corrêa et al. [91] developed a VR dental anesthetic training simulator in the inferior alveolar nerve block. The simulator emulates the tactile sensation of actually inserting a needle into a patient by capturing the forces exerted on the simulator by the student using VR techniques and a haptic device named Phantom Omni, which records the student's movements, including rotation and position, and then reproducing them in a 3D virtual environment.
3) Miki et al. [90] demonstrated the construction of a training employing virtual reality simulation of submandibular gland ectomy with endoscopic assistance (refer Fig. 19). After activating the haptic device, the VR system simulates the motion of forceps on the monitor's display. Three layers of connective tissue, a globe resembling the submandibular gland, and a blood artery were included in the VR images, the last two concealed under the connective tissue. Structures were projected into the virtual reality imagery created as virtual objects using OpenGL, a 3D graphics rendering engine. Each virtual item is given an elasticity and hardness value, which enables the synthetic tissues' motion and elasticity to be adjusted to imitate a variety of clinical circumstances. The VR simulator included:
    - A computer system (Windows 7 Professional SP3 32-bit operating system, 4GB DDR2 SDRAM memory, NVIDIA Quadro FX 1800 768 MB graphics).
    - A 23-inch monitor.
    - Two Geomagic Touch haptic devices.

    Geomagic Touch utilizes Geomagic Freeform and is compatible with VR force feedback devices. The device's specifications are Range of motion: hand movement pivoting at the wrist; maximum force sensed: 3.3 N; force feedback: 3-axis (x, y, z); and interface: IEEE-1394 FireWire. Several virtual tools for touching and abrasion, which are crucial abilities for endoscope-assisted surgery, were provided in the Geomagic Freeform program, allowing us to manipulate virtual objects using the forceps on the device handle. By pressing a button on the original device's handle, the functioning of the forceps in VR replicated the opening and closing of Pean forceps. To simulate reality as accurately as possible, the Pean forceps used during the operation were attached to the original device's handle.

The Pean forceps were equipped with a magnetic reed switch to transfer signals. This allowed for the simulation of interactions comparable to those encountered during actual surgical procedures.

Some of the additional applications of surgical training are the usage of VR simulations in training orthopedic surgery residents in arthroplasty (a surgical procedure to restore the function of a joint) such as total hip arthroplasty training [93], glenoid (part of the shoulder joint) exposure in shoulder arthroplasty training [94], and knee arthroscopy [95]. [95] reviews some more applications in orthopedic surgical training, such as spinal pedicle screw placement [96], [97], [98], tibial shaft fracture fixation [99], pre-surgery fracture carving [100], and dynamic hip screw placement [101].

To help the readers, we summarise all the metaverse applications in the domain of education and learning in Table 2. The case studies show that even though there is great scope for improvement, the metaverse has already shown great potential. We highlight the major benefits of the metaverse in medical learning as:

1) The primary advantage of the metaverse for e-Learning is its ability to bring online learning environments to life. Educators are able to construct venues that meet their instructional requirements.
2) Metaverse enables students to engage with objects as if it was real and apply concepts in theory into practice. It gives the virtual classroom a more incredible feeling of reality, keeping students interested in the learning process.
3) Instructors and students might experience emotions of isolation and loneliness when separated by distance. To combat these sentiments and encourage interaction, the metaverse enables teachers to build rooms for internal meetings. Concurrently, students may construct study rooms where they can cooperate, study together, and interact socially. These features encourage students to interact with their peers and teachers, boosting the learning experience.
4) 3D illustrations may assist viewers in comprehending how a particular piece of equipment operates or what a mathematical notion looks like in the real world.
5) For many years, the advantages of gamified learning have been recognized. It promotes problem-solving, provides instantaneous feedback, and improves the overall learning experience.

VI. CLINICAL CARE

A healthcare center, health center, or community health center is one of a network of clinics staffed by a group of general practitioners and registered nurses that provide healthcare services to the residents of a particular region. The services of a health center can include pediatric, women's care, family planning, pharmacy, orthopedics, etc. In this section, we depict the metaverse can provide immersive experiences that could provide real-time guidance in the physician's field of view. The domains of health centers considered are summarised in Figure 20.

A. ORTHOPEDICS

Orthopedics is the branch of medicine concerned with the maintenance and preservation of the function of the skeletal system and its related structures, i.e., the spinal and other bones, joints, and muscles. The applications are:

1) Johns Hopkins neurosurgeons [102] have performed augmented reality surgeries on living patients, beginning with a spinal fusion surgery to fuse three vertebrae to ease chronic, excruciating back pain and the excision of a malignant tumor known as a chordoma from the spine. The physicians employed headset technology made by an Israeli company, Augmedics, with a crystal clear display to project visuals of the patient's interior anatomies, such as bones and other tissue, based on CT scans, thus giving the surgeons X-ray vision, as seen in Figure 21. Dr. Witham, who led the spinal fusion surgery, described the experience as "like having a GPS navigator in front of your eyes in a natural way," avoiding the need to take a glance at a separate screen repeatedly to see the patient's CT image during the duration of the surgery.
2) AccuVein (Figure 22) superimposes a map of the patient's veins onto the skin using projection techniques, which can potentially assist intravenous injections [103]. AccuVein employs projection-based AR and vein visualization technology. Using a laser-based scanner, processing system, and digital laser projection in a compact, handheld device, users may observe a virtual, real-time picture of the underlying vasculature on the skin's surface. For vein detection, vein visualization uses Near-Infrared (NIR) imaging technology. This established technique permits precise viewing of the veins under the skin. The AccuVein utilizes two safe lasers of the barcode-scanner class: an invisible infrared laser and a visible red laser. Together, the two lasers offer a real-time view of the subcutaneous vasculature up to 10 mm deep. First, the hemoglobin in the blood absorbs infrared light, resulting in less light reflection from the veins. A proprietary detecting system then uses this shift to establish vein location and pattern, which it digitally displays onto the skin's surface. Finally, the green laser makes the vein mapping visible to the doctor.

Thus, metaverse can allow practitioners to project medical pictures, such as CT (Computed Tomography) scans, directly onto the patient and in alignment with their bodies, even while the patient is moving, giving them a better view of interior anatomy.

B. OBSTETRICS

Obstetrics is the study of pregnancy, delivery, and postpartum care. Obstetrics and gynecology is a surgical profession that

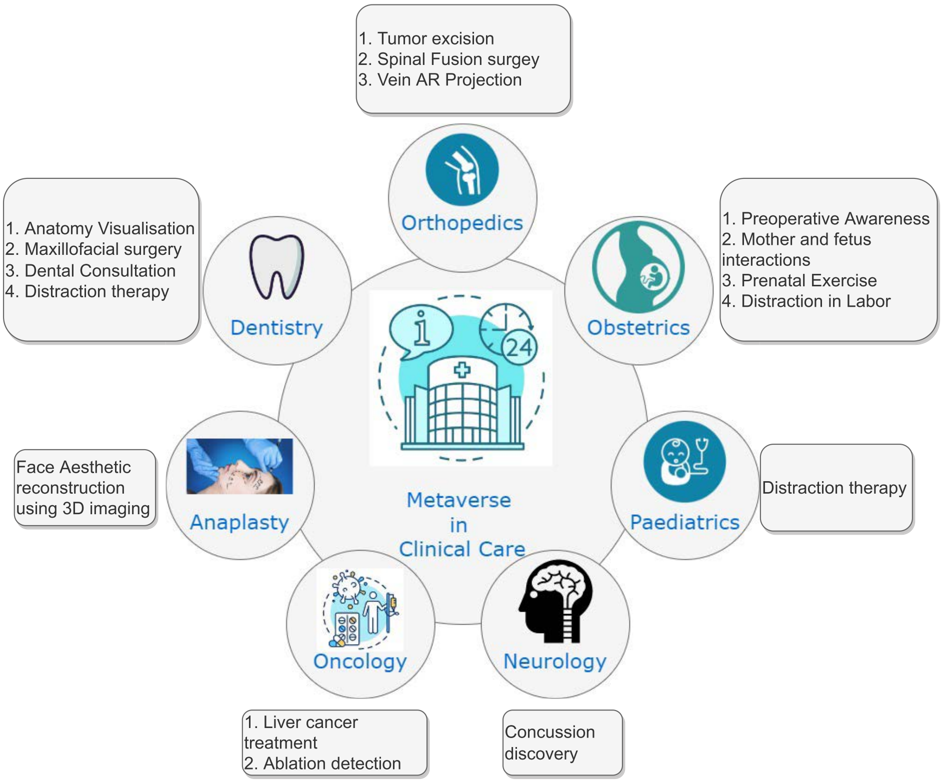

FIGURE 20. **Overview of metaverse applications in different divisions of clinical care.**

FIGURE 21. **Surgeons using AR headsets to project visuals of the patient's internal anatomies [102].**

combines the medical specialties of obstetrics and gynecology. Metaverse is being utilized to help pregnant women have a better pregnancy by lowering their anxiety levels and teaching them how to successfully control their pain during labor. Anxiety and stress have negative medical, biological, mental, and behavioral repercussions on the mother and her child during pregnancy. During labor, a pregnant woman's heart rate and blood pressure rise, reducing the blood flow rate in the uterus. Anxiety can also increase the amount of pain experienced after delivery, as well as the risk of postpartum depression. Metaverse technology, as a non-pharmacological technique, can create a virtual world and divert patients' attention away from pain signals during pregnancy to something else [105]. Some of the applications in obstetrics are:

1) Sridhar et al. utilized VR techniques to alleviate anxiety during the first-trimester dilation and curettage surgery procedures [106].

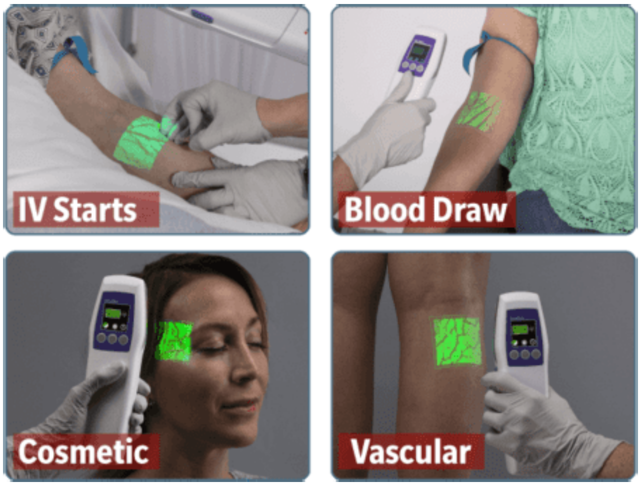

FIGURE 22. Map of the patient's veins projected onto the skin using AccuVein technology [103].

FIGURE 23. A pregnant woman using a VR headset to view a simulated beach area alleviates discomfort during the early stages of labor [104].

2) Noben et al. employed metaverse to educate pregnant women about cesarean surgery and to alleviate their anxiety before the procedure [107].
3) Jahani et al. utilized metaverse to help primiparous women who needed episiotomy repair feel less anxious [108]. The work used Wrap 920 Video Eyewear from Vuzix, which supports multi-anaglyph and side-by-side formats. In addition, a 3D Blu-Ray Player of model BD660 with a connecting cable and composite input is used in the system.
4) Sevenri et al., using ultrasound images, generated a 3D model of the fetus [109] for enabling virtual haptic and visual contact between the mother and her fetus, thereby providing a virtual fetal touch to enhance the engagement between a mother and her fetus and alleviate any anxiety a woman may be experiencing during her pregnancy.
5) In [104], NHS hospital provides pregnant women with virtual reality headsets that allow them to relax virtually in simulated environments such as the beach and planet Mars, distracting them from the delivery pain (Figure 23).

FIGURE 24. KindVR develops VR therapies to assist patients in coping with pain and stress [112].

6) Virtual reality is being used by Mosso et al. to reduce pain and anxiety during cesarean surgery [110].
7) Setiawan et al. created a VR application including training for various exercise activities that could help pregnant women enhance their physical activity [111]. This program is designed to work on the Mobile VR platform in Xiaomi Redmi Note 4 smartphone using the VR Shinecon headset.
8) The work in [105] presented VR-based exercise during pregnancy that may aid in the management of gestational diabetes, the reduction of cesarean surgery rates, and the promotion of healthy fetal and maternal weight gain.

C. PAEDIATRICS

Pediatrics is a medical specialty concerned with treating newborns, children, and adolescents. Among the metaverse applications in Paediatrics is KindVR [112]. Young toddlers are transported to a virtual world while receiving vaccinations at Brazil's Hermes Pardini vaccine center (Figure 24). The theory underlying these treatments is based on distraction therapy. A kid is encouraged to cope with a painful or difficult treatment by diverting the child's attention away from the actual procedure and directing it toward something else. While these methods are successful, their effectiveness varies from person to person. Affective computing aims to develop computers capable enough to change their behavior in response to the user's current mood. The game responds to the child's emotions, therefore increasing the child's comfort and sense of well-being. For example, if the child feels a scorching sensation, the game's environment is altered to include dragons and other characters to justify the emotion. As a result, the youngster becomes more engrossed in the game, resulting in a more effective and less unpleasant intervention [113].

D. NEUROLOGY

Neurology is a branch of medicine concerned with abnormalities of the nervous system. Neurology is concerned with

FIGURE 25. Concussion diagnosis using SyncThink's eye-tracking technology [114].

diagnosing and treating all illnesses and diseases affecting the central and peripheral nervous systems and their coverings, blood vessels, and all effector tissues, such as muscle. Eye-Sync [114], a VR headgear developed by SyncThink, is the best example of metaverse application in the field of neurology. It aids athletes in their recovery once a brain impairment is discovered using eye-tracking technology. In sports, half of the concussions go unreported or undiscovered. One of the difficulties for team medics is that brain impairment is difficult to identify when there are no apparent injuries or the full-time whistle right after impact. The Eye-Sync platform from SyncThink incorporates a VR headset. When a user puts on the VR goggles, Eye-Sync can run through tests that monitor and analyze eye movement and record data, processed using a cloud-based software application. Because it can forecast how the dot travels, a healthy brain should be able to properly follow the path (Figure 25). The VR headset utilizes infrared cameras to monitor eye movement. These photos are then used to develop a model of the patient's eye and estimate the direction of the patient's sight. Subsequently, the transmitted data is delivered through the Eye-Sync cloud and a 4G Android tablet. Tablet may not always have a consistent cellular connection; thus, a data platform from Couchbase Server allows the tests to be executed even when the tablet is offline. When the connection is available, the data on the tablet may be synchronized with the central database. When a concussion or brain damage occurs, however, the connections between the brain and eyes are compromised, resulting in visual performance and eye movement abnormalities [115].

E. ONCOLOGY

Oncology is a branch of medicine for cancer prevention, diagnosis, and treatment. The Cleveland Clinic, a not-for-profit, academic medical center in Ohio, has developed a method to improve liver cancer treatment by increasing the precision and efficacy of a minimally invasive thermal treatment called microwave ablation used to destroy liver tumors using the Microsoft HoloLens device [116]. Apart from liver cancer therapy, they are also using it to treat aortic aneurysms,

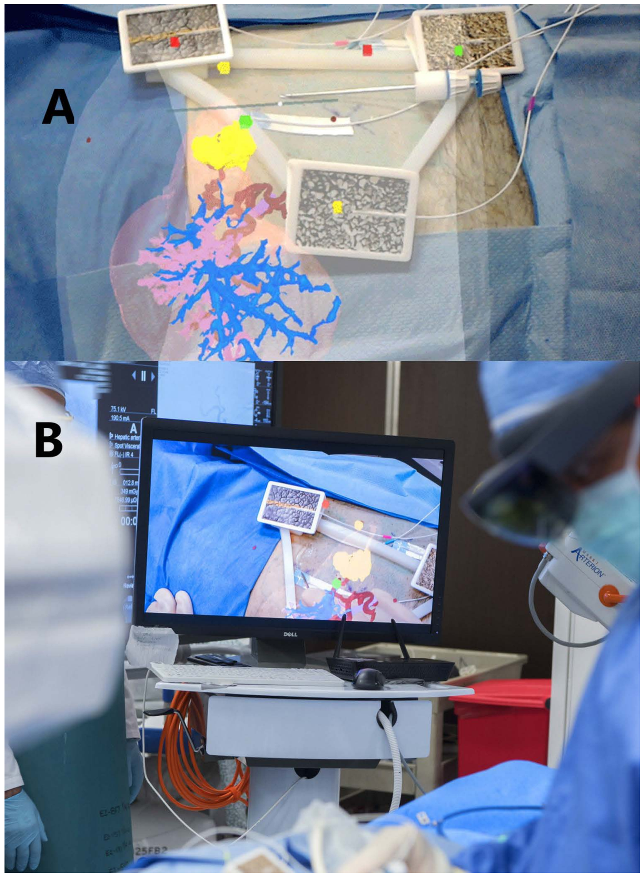

FIGURE 26. A. 3D representation of a patient's anatomy by Dr. Martin while wearing the HoloLens during preoperative planning to remove a malignant tumor (tumor shown in yellow). B. 3D holographic picture developed with Microsoft HoloLens is presented on a monitor in the operating room during a liver tumor operation [116].

face transplant surgery, and ovarian cancer. With the use of Microsoft HoloLens, 3D holographic visuals are projected onto the patient (as seen in Figure 26), providing the doctor with "X-ray vision" to comprehend a better route to the tumor in comparison to the 2D standard of care images displayed on a typical flat panel screen. The radiologist may more accurately guide a biopsy needle into the tumor using these holographic representations. The doctor next burns and kills the abnormal tumor tissue through the needle using microwave radiation. The physician wears a Microsoft HoloLens on their head to see the patient's inner anatomical characteristics and confirm tumor location utilizing the technology's mini-GPS.

F. ANAPLASTY

Anaplasty is the branch of surgery concerned with the therapeutic or aesthetic reconstruction or re-formation of missing, damaged, or deformed tissues or body parts. Cleveland Clinic performed face transplantation using Microsoft HoloLens. The technique begins with CT scans of the donor's face, segmented to extract the information essential for the future transplant operation and imported into the Microsoft

FIGURE 27. A. The HoloLens is in use during the face transplant procedure. B. Surgeons consult a 3D-printed stereolithographic model of the recipient's face during the transplantation procedure [117].

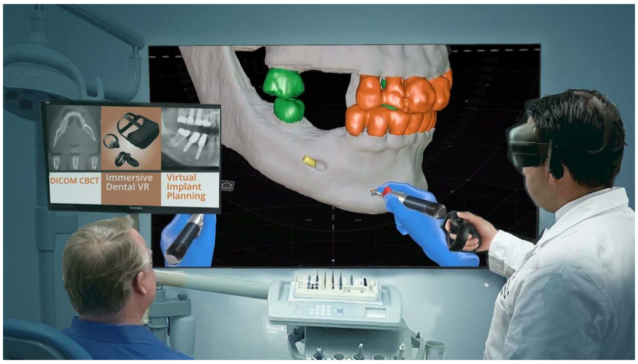

FIGURE 28. Office consultation with patient using VR headset to elaborate the patient's case by virtually simulating the surgery [124].

HoloLens system [117]. The HoloLens equipment is then used to superimpose a 3D holographic image of the donor's anatomy onto the recipient's face, enabling the recipient to check alignment and adjust their facial surgery plan accordingly, as seen in Figure 27. This technology enabled the doctors to walk around the holographic image and analyze the anatomy effectively. The patient-specific pictures for the transplant candidate were created from their CT data and mapped to their face using markers, allowing surgeons to see the DICOM or CT data set overlaid on the patient's face as a complete representation in the form of 3D images. Extrapolating the skull, skeletal components, and vascular structures enabled surgeons to visualize their interconnections and plan their surgical strategy. In addition to the 3D holographic image generated by Microsoft HoloLens, they had also developed 3D-printed stereolithographic models (as shown in Figure 27) for both the donor and recipient's faces. The 3D-printed models used in the preceding two face transplants at Cleveland Clinic effectively visualized more prominent structures from the CT data collected.

G. DENTISTRY

Dentistry, also known as dental medicine or oral medicine, is a branch of medicine that deals with the study, diagnosis, prevention, and treatment of illnesses, disorders, and conditions of the oral cavity (the mouth), typically in the dentition

FIGURE 29. Metaverse used in distraction therapy for effective pain management [125].

(development and arrangement of teeth) and oral mucosa, and of adjacent and related structures and tissues, especially in the associated maxillofacial (jaw and facial) region. Dentistry or dental medicine includes teeth and other components of the craniofacial complex, such as the temporomandibular joint and associated supporting muscular, lymphatic, nervous, vascular, and anatomical tissues. Metaverse has found its way into the field of clinical dentistry in various applications such as:

1) Metaverse technology is used in distraction therapy for effective pain management during dental surgeries [125]. VR headsets make office consultations with patients easier for the doctors to elaborate on the patient's case by virtually simulating the surgery. An example of VR technology in clinical dentistry is Immersive Dental, which provides clinicians with virtual implant simulations to help them plan and practice implant surgery. This will assist in reducing the amount of implant time required before each surgery. Thus reducing stress and enhancing the quality of patient care (Figure 29).
2) The treatment of lesions in the cavernous sinus region is carried out using skull base surgery, and it is essential to work out its 3D anatomical structure before surgery. Cadaver dissection is the conventional method used for its treatment but possesses challenges that are difficult to overcome in comprehending spatial anatomy. Therefore, a metaverse system [119] is proposed that accurately describes the whole and local dental stereo-anatomy.
3) At the University of Geneva, a recurring intraorbital tumor was removed with the help of AR technology [120]. Their microscope-based approach aided in characterizing the tumor's deep extension into the orbital roof by locating the posterior third of the lesion for dissection and validating its entire eradication. Due to the microscope's focal point, it was employed to virtually probe and correlate the surgical fields

TABLE 3. Study of different metaverse in clinical care.

Work	Category	Area	Company/Location	Augmented Reality	Virtual Reality	Simulations
[102]	Orthopedics	Spinal	John Hopkins University, USA	Yes	No	No
[103]		Anatomy	Accuvein	Yes	No	No
[107]	Obstetrics	Preoperative Awareness		No	Yes	Yes
[109]		Mother and fetus interaction		No	Yes	Yes
[106]		First-trimester miscarriage		No	Yes	Yes
[111]		Prenatal Exercise	-	No	Yes	Yes
[105]			-	No	Yes	Yes
[108]		Labor	-	No	Yes	Yes
[104]			NHS Hospital, UK	No	Yes	Yes
[110]			-	No	Yes	Yes
[118]			-	No	Yes	Yes
[112], [113]	Paediatrics	Distraction therapy	Brazil's Hermes Pardini	No	Yes	Yes
[114], [115]	Neurology	Concussion	-	Yes	No	No
[116]	Oncology	Liver cancer	Cleveland Clinic, Ohio	Yes	Yes	Yes
[117]	Anaplasty	Face transplant	Cleveland Clinic, Ohio	Yes	Yes	Yes
[119]	Dentistry	Anatomy	-	No	Yes	Yes
[120]		Maxillofacial surgery	University of Geneva	Yes	No	No
[121]			-	No	Yes	Yes
[122]			-	Yes	No	No
[123]			-	No	Yes	Yes
[124]		Consultation	-	Yes	No	No
[125]		Distraction therapy	-	No	Yes	Yes

and navigation pictures. The microscope was tracked using a neuro-navigation system, and segmented, three-dimensional virtual images of the tumor were projected onto the surface of the patient's skin following its position, providing the surgeon with an enlarged and stereoscopic view of the surgical field, confirming complete tumor removal.

4) Qu et al. [122] used an AR Toolkit to develop an effective navigation strategy for distraction osteogenesis in patients with hemifacial microsomia to identify the mandibular osteotomy line and aid in intraoral distractor placement. Through 3D real-time images, AR can give an idea of the anatomical structure or visual signals for particular locations. A surgical site may be superimposed with a "see-through" graphic created using AR, which permits virtual imagery creation from computer-generated datasets. AR technology generates three-dimensional images of the mandible with a pre-built cutting plane on surgical sites, serving as a surgical aid for transferring the osteotomy lines and screw locations.
5) Yamada et al. [121] conducted research to assess the effectiveness of mandibular restorations employing a custom-made titanium mesh (Ti-mesh) tray and particle cancellous bone and marrow (PCBM) using VR simulations. Virtual reality simulations were created using computer software and preoperative computed tomography data. A 3D printed skull model was developed, and a tray built from a Ti-mesh sheet bent to suit the model was custom-made. After PCBM harvesting, the tray was attached to the host bone, and the reconstructed mandible's new bone development and configuration were evaluated radiographically.
6) Zinser et al. [123] conducted a project comparing surgical transfer of virtual orthognathic planning to navigation, CAD/CAM-based splints, and intermaxillary splints. Maxillo-facial imaging, virtual orthognathic planning, diagnosis, and surgical planning transfer were analyzed using intraoperative navigation, newly designed CAD/CAM splints, and intermaxillary occlusal splints. This study concluded that CAD/CAM splints and surgical navigation provided a sound, ingenious, and accurate method for transferring virtual orthognathic planning.

Overall, surgical simulations, patient care management, diagnostic imaging, health management, and rehabilitation [126] is considered to be the essential use of the metaverse in the field of clinical care. These technologies can help patients learn more quickly about their diseases or treatment options. The summary of works for clinical care is shown in Table 2.

VII. PHYSICAL WELLBEING

Physical fitness is a condition of health and well-being, and more precisely, the ability to participate in day-to-day activities without undue fatigue or physical stress. Since people are lazy to engage in physical activity, gamification is a relatively novel method of linking healthcare providers and patients, particularly in the wellness and fitness sectors, where AR may give better exercises with virtual teachers' supervision. Players are incentivized to participate in another new idea known as "move-to-earn." For example, in Genopets [129], players may get points for walking, dancing, running, or simply waking up and going about their regular lives utilizing data from cellphones and wearables. Some applications are:

FIGURE 30. Supernatural, a VR fitness game that offers whole body workouts [127].

FIGURE 31. Bodycombat VR, a total body martial arts workout game played using Oculus Quest 2 [128].

1) Supernatural [127], [130] is a VR fitness game that enables players to access the virtual reality environment using the Oculus Quest headset, as demonstrated in the picture 30. Supernatural is similar to Beat Saber, a VR rhythm game [131] where the users slash the beats of adrenaline-pumping music as it approaches the user in a simulated environment in the form of a futuristic world. The app has succeeded in generating cardiovascular routines centered on movement. In Supernatural, the user must hit colored orbs flying from various VR environments using the controllers. Each exercise on the app comprises music-mapped regimens that users can complete anywhere. Under Meta Reality Labs, Supernatural will continue to operate autonomously and develop VR-based fitness, health, and social experiences.
2) Les Mills [128], [132], a popular fitness club, has entered the metaverse with Bodycombat VR. This VR game extends the company's current workout series that blends shadowboxing and martial arts and is accessible on the Meta Quest platform. Classic boxing movements like jabs, hooks, and uppercuts are used, and squats and slides to avoid barriers have made their way into this game. Other actions involve snatching things and slamming them into the knees of the user. Players score points for technique and effort, and levels are set against "intergalactic deserts and neo-city skylines," as shown in Figure 31.

VIII. PHARMACEUTICALS

The pharmaceutical industry discovers, develops, manufactures, and distributes drugs or pharmaceutical products intended for administration to patients to cure, immunize, or relieve symptoms. The applications are:

1) Sygnature Discovery, a drug discovery company based in England, has harnessed metaverse's capabilities to make a breakthrough discovery involving monitoring chemical compounds in new medications using a 3D virtual environment. As demonstrated in Figure 32, they employed AR to spin virtual molecules and form chemical structures. They constructed VisMol, a system that leverages Microsoft HoloLens technology to build an augmented reality environment, allowing someone wearing the HoloLens headset to view computer-generated molecular models in the real world [133].
2) iMining Technologies [134] owned subsidiary, Metaverse Advisory Group ("MAG") is supporting Noman Qureshi's Pharmacy Group in formulating and implementing its digital and metaverse-related strategies. In the metaverse, MAG will supply the Pharmacy Group with an online, AI-enabled e-commerce platform for their pharmaceutical business. The world's first metaverse pharmacy will be opened in Decentraland [135], a 3D virtual world browser-based platform where users may buy virtual plots of land on the platform as NFTs via the MANA cryptocurrency (in-game currency of Decentraland and also serves as the platform's cryptocurrency), which uses the Ethereum blockchain, a decentralized blockchain platform that establishes a peer-to-peer network that securely executes and verifies application code, called smart contracts. The metaverse pharmacy promises to increase drug adherence by allowing patients to schedule automatic refill reminders for prescription medications delivered directly to their homes. Customers can also make appointments for pharmacy services through the metaverse pharmacy, such as online consultations with licensed pharmacists.

IX. MENTAL WELLNESS

Mental health includes our emotional, psychological, and social well-being. It impacts our thoughts, feelings, and actions. It also influences how we deal with stress, interacts with people, and make good decisions. Mental health is essential throughout all stages of life, from childhood and adolescence through adulthood. Extended-reality headsets can be utilized to manipulate users' psychological experiences to treat addictions and phobias [138]. Some examples are:

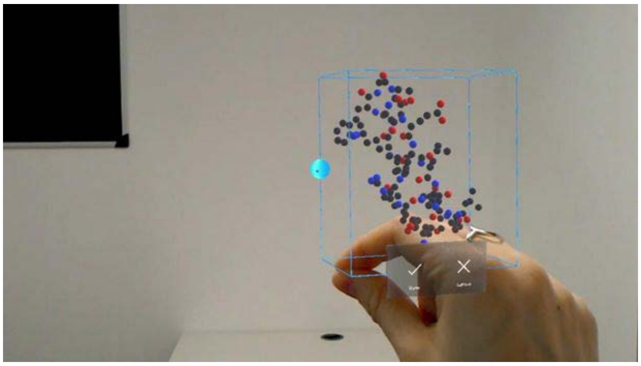

FIGURE 32. Creating chemical structures using Sygnature discovery [133].

1) Virtual Reality Exposure Therapy (VRET) has been beneficial in treating particular phobias [138]. VRET employs cutting-edge technology to simulate accurate contact with fear-inducing stimuli through visual and aural sensory channels, acting the interaction as closely as feasible with standard exposure treatment protocols. The therapist has complete control over the program, including the option to start and stop it at any time, pick where it runs, adjust the intensity of the interaction, and stop it immediately if the patient feels overwhelmed to prevent any medical consequences. Because the features that the patient fears are virtual, they cannot physically damage them, and neither the patient nor the therapist is in danger. Patients may watch a safe artificial environment rather than conceive the situation in their brains or travel elsewhere to immerse themselves in a stressful setting, which is particularly important for circumstances that are difficult to envisage or put a patient in such a situation as a flying phobia. Because VRET systems may be set up anywhere, they are more attractive to those with social phobias or other conditions that restrict them from traveling. Younger patients may be persuaded to engage in treatment since VR technology fascinates them and offers the impression of being non-clinical. The most significant disadvantage of VRET is the danger of cybersickness in persons already suffering from anxiety-inducing disorders such as [138].
2) Dr. Rizzo, Director of Medical VR at the University of Southern California, created Bravemind, a virtual reality exposure treatment aimed at reducing post-traumatic stress disorder (PTSD), notably among veterans of the Iraq and Afghanistan conflicts [136]. As seen in Figure 33, during exposure treatment, a patient confronts their trauma memories via simulations of their events, helped by a skilled therapist. Figure 33 demonstrates how, by wearing a headset, the patient may be immersed in various virtual environments, including a Middle-Eastern-themed metropolis and desert road landscapes. The user is provided with a computer-generated image of a virtual environment that responds naturally to head and body movements. In some scenarios, users carry a second position sensor or interface controller that allows them to alter their surroundings and explore the virtual world. VR environments presented in his work differ from conventionally displayed programs, as computer graphics displayed on the head-mounted display are augmented with motion tracking, vibration platforms, localizable 3D sounds within the VR space, and, in some cases, scent delivery technology to facilitate an interactive environment for participants. Patients use a keyboard to replicate people, insurgents, explosions, and even odors and sensations, enabling them to experience an event in a secure, virtual setting rather than just imagining it. It is anticipated that it will be a viable alternative to conventional conversation therapy [81].
3) Compared to VRET, Augmented Reality Exposure Therapy (ARET) offers several benefits. AR has a more excellent feeling of presence (the impression of being present) and reality judgment (judging events as accurate) than VR because the surroundings and components the patient utilizes to connect with the program are authentic. Furthermore, AR users may be able to see their own hands and feet, enabling them to align spatially and engage more naturally with their real-world situations, reducing cybersickness [138]. Juan et al. [137] performed the first-ever research using augmented reality to identify and treat various phobias. The experiment was performed on a single subject who had a cockroach fear. The patient was exposed to virtual cockroaches using an AR headset, and the session consisted of observing, touching, and ultimately eliminating one or more virtual cockroaches. A USB camera (Creative NX-Ultra) records the video feed. MR images are shown using a 5DT HMD. The camera is connected to the HMD. ARcockroach, the augmented reality system used to treat cockroach fear in this research, was created using ARToolkit 2.65 software with VRML support (Virtual Reality Modeling Language, a standard file format for representing 3D interactive vector graphics). During the treatment, the individual, would hold the marker (a 2D item that functions as a visual trigger), which the camera in the AR system would identify. After the camera recognizes the tag, the virtual elements (cockroaches) emerge in front of the participant, and the camera follows the surrounding components (Figure 34) [137].
4) Raghav et al. [139] developed an innovative non-invasive VRET technique that may provide an alternate treatment for dental anxiety and phobia. The research examined the effectiveness of VRET in terms of state anxiety reductions, dental traits, and physiological arousal in real-time, such as heart rate. Virtual Simulations Inc., in partnership with KR and ADJ, created the VRET program for this study. The hardware consists of two networked computers: the VR-simulator

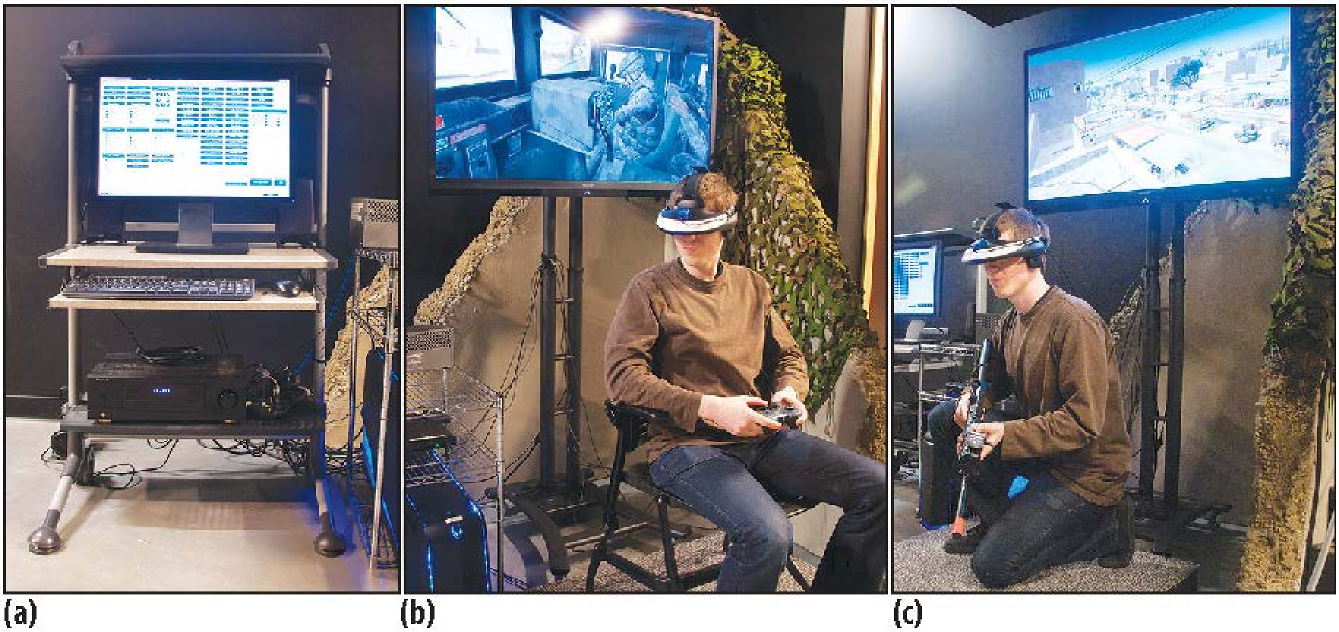

FIGURE 33. Components of the Bravemind system in action. (a) A clinician interface for real-time adjustment of VR settings to accommodate user experiences. (b) A seated participant employs VR head-mounted display and a standard joystick in a driving scenario. (c) Mini-gamepad fitted to a rifle for operation in a walking scenario [136].

PC depicts the virtual world. The User interface-PC (UI-PC) enables the clinician to manage and customize the stimuli delivered. The VR simulator program will build the VR dental environment utilizing a Dell XPS-8700 PC with a 4th Generation Intel Core i7-4790 CPU (8 MB Cache, up to 4.0 GHz) and an ASUS NVIDIA GEFORCE GTX 750 TI OC 2GB GDDR5 video card. To immerse the participants in the virtual reality dental environment, an Oculus development kit with two HMDs with a resolution of 960 $\times$ 1080 per eye and a field of vision of 100 degrees is used (nominal). A tripod-mounted Oculus positional tracking camera monitors head movements in real time. For VRET, a replicated dental setting was created, complete with an overhead light, dental chair, dental tools, and drips of clove oil on cotton wool to increase immersion characteristics such as dental clinic-related scent. The test volunteers were forced to recline on an actual dental chair while looking about and seeing their virtual counterparts within the HMD. The test participants were put through five distinct situations. These scenarios depicted a dentist's workstation with multiple instruments surrounding the patient's chair, a virtual dentist sitting beside the patient's right hand within the 3D scene, picking up the dentist's mirror from the tray to examine the oral cavity and approaching the patient's oral cavity, and the virtual dentist injecting the patient by picking up the syringe from the tray and approaching the patient's oral cavity.

5) gameChange, a VR application programmed by Oxford VR, is used for automated VR therapy to treat agoraphobic avoidance and distress in patients with psychosis who are anxious about everyday social situations [140]. Agoraphobia refers to a type of anxiety disorder in which the victims fear and avoid places or situations that might cause them to panic and feel trapped, helpless, or embarrassed. gameChange clinical trials utilized an HTC Vive Pro headset and a laptop. Over six sessions, patients practice being in VR simulations of common scenarios of public places such as a cafe, shop, street, etc., and a virtual therapist guides the patient through the program, thereby enhancing access to effective psychological therapy.
6) An immersive VR training system called VRADA (VR Exercise App for Dementia and Alzheimer's Patients) is used to treat people diagnosed with mild cognitive impairment (MCI) [141]. VRADA allows older people with MCI symptoms to simultaneously practice physical and cognitive skills on a dual task, which is considered an effective treatment modality for mental and physical training in MCI-diagnosed patients. VRADA app was built on top of the ORamaVR MAGES platform using the training and interaction mechanics of MAGES SDK. The VRADA app utilizes Oculus Go, a standalone, untethered headset, as the main VR head-mounted display. The untethered nature of Oculus Go makes the device ideal for exercise purposes. A cycle ergometer (stationary seated bike type; Toorx, Chrono Line, BRX R 300) was considered the optimal choice for the exercise apparatus, as it reduces user fall risk and facilitates precise control of training conditions. The patients are supposed to cycle using the cycle

FIGURE 34. Augmented reality exposure therapy using a marker for treatment of phobia of cockroaches [137].

ergometer and simultaneously solve simple numerical calculations during cycling. VRADA provides flexibility in clinical settings as it can be tailored to the individual needs of each patient and facilitate training in environments that are unsafe in the real world. Combined with functional magnetic resonance imaging, brain functionality can be tracked in the VR world. Another application in mental wellness is the VEPSY project, a European Community-funded research project which emphasizes the importance of VR in clinical psychology [142]. VEPSY aimed to design and develop VR-based tools targeting the following disorders: panic disorder, social phobia, and agoraphobia; male impotence and premature ejaculation; obesity, bulimia, and binge-eating disorders.

X. VETERINARY

Metaverse application is not limited to the human healthcare industry but extends to extended healthcare domains such as veterinary. The term veterinary is used to designate a person whose duty it is to treat ill or wounded animals, as well as the medical care of animals. Some of the applications are:

1) Deepfake technology is a sort of artificial intelligence (AI) used to make convincing synthetic pictures, audio, and video duplicates of existing material. Figure 35 by Neethirajan [143] illustrates how data augmentation, in the form of digital twins, digital avatars, or metaverse, is a modern tool for examining the intricacies of animal cognition and behavior to improve farm animal welfare. Deepfake technology can significantly enhance animal health, sociality, emotionality, and animal-human and animal-computer interactions, increasing the agricultural industry's productivity and sustainability. Animal activity and mobility are continually recorded using ML and AI to improve welfare or disease-related metrics. Emotions in animals have been connected to specific vocalizations, eye temperature, hormone levels, and facial expressions.
2) At the RusMoloko farm outside Moscow [144], [145], Russian farmers have spent years attempting to increase their cows' milk production. Initially, classical music was utilized, which appeared to have favorable effects. However, the outcomes were not particularly outstanding. They decided to take a different approach and implement VR for animals on their cattle. Together with vets and IT specialists, they were able to design a VR headset for their cows. According to their reports, the technological experiment was highly successful. According to Russian farmers, cows that wore the VR headset for animals produced 22-27 liters more milk per day. It has a far more substantial impact than classical music, which is astounding. VR goggles for animals provided the cows with images of a meadow. Thus, the simulation was more enjoyable, especially in comparison to their captivity. The notion was that the cows were less stressed and happier, resulting in increased milk production.

XI. CHALLENGES

Having discussed the prospects of the metaverse in the healthcare industry, it is imperative also to understand the challenges that need to be tackled before wide adoption of the metaverse is possible (Table 4). The study [15] emphasizes the need for prudence while adopting the notion of the metaverse since it constitutes fundamental narratives driving technology design and global politics and is intended to integrate seamlessly with the present physical world. In cloud data storage, for "digital assets" acquired with bitcoin, and for real online playing time, these new technologies demand enormous amounts of energy. Although 5G will reduce the energy cost per unit of data, it will increase energy consumption relative to earlier technologies. Carbon offsetting is not the same as biodiversity, therefore the carbon consumption measure by itself is inaccurate. If the metaverse is not handled appropriately, it poses a danger to the well-being. The potential magnitude of disruption posed by the metaverse is immense:

1) It can swiftly accommodate enormous populations.
2) It might take years to determine the implications of negative affects.
3) These effects may be difficult to reverse. For instance, a significant portion of the education and money required for a high quality of life is connected to employment.

The challenges of the metaverse are:

A. HARDWARE

The metaverse is highly dependent on VR, AR, and MR devices. Because most of these devices are neither

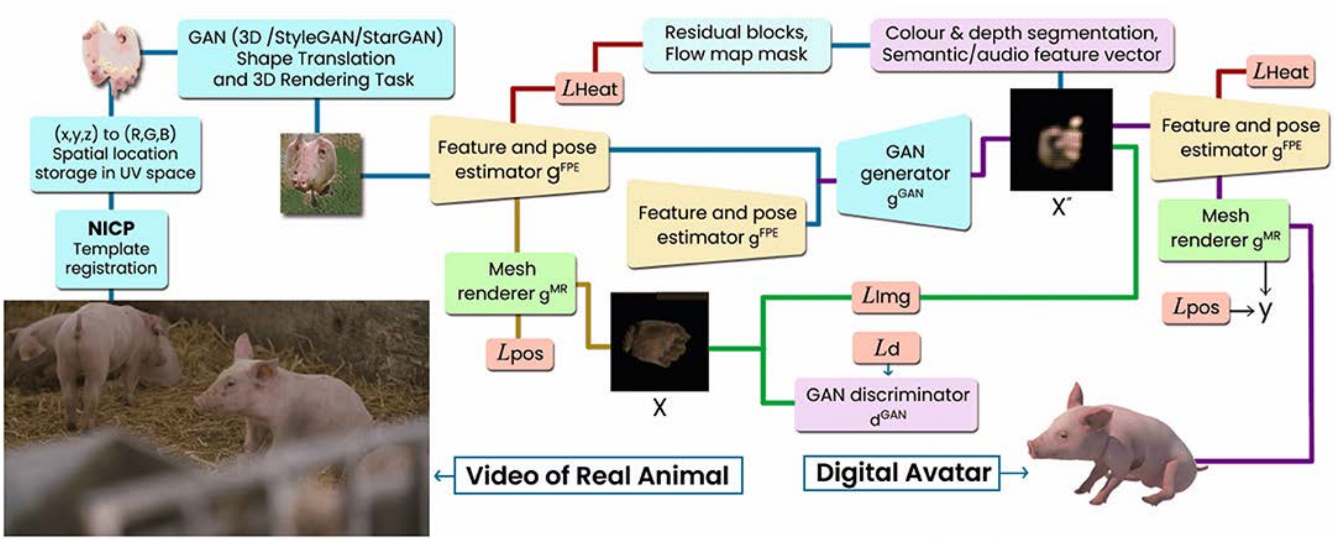

FIGURE 35. Leveraging deepfake technology for livestock farming [143].

TABLE 4. Challenges to the metaverse.

Sequence	Category	Challenges
1	**Hardware**	1. Requirement of intricate devices 2. Not readily available 3. Bulky, heavy and costly
2	**Authoring Toolkits**	1. Complex multiplex aggregation 2. limited software tools available 3. Lack of precision and accuracy 4. Irregular synchronisation among devices
3	**Privacy and Data Security**	1. Data breaches 2. Storage of user activity 3. Lack of user privacy 4. Huge data/passwords
4	**Identity Hacking**	1. Cloning using bots 2. Hacking 3. Avatar invalidation
5	**Addiction and Mental Health**	1. Addictive 2. No social interaction beyond metaverse 3. Anxiety 4. Mental Illness
6	**Currency and Digital Payments**	1. Multiple cryptocurrency 2. No check and balance system 3. Speedy and frictionless transactions 4. Billions of users
7	**Law and Jurisdiction**	1. Virtual crimes 2. Conflict of International border crimes 3. Varied laws and jurisdiction

lightweight, portable, or affordable, the metaverse cannot currently be broadly embraced. Aside from hardware availability, having high-quality and high-performance models that can achieve the accurate retina display and pixel density for a realistic virtual immersion is significantly difficult [146].

B. AUTHORING TOOLKITS

Metaverse authoring requires aggregating different streams of media contents like text, audio, image, animations, and video as a single stream of information with the help of various software tools available. Metaverse authoring tools give an integrated environment for joining together the different elements of a metaverse system. However, authoring tools currently present in the market have several limitations, such as failure of object recognition system next to boundary edges, inducing cybersickness in certain events of a simulation, irregular synchronization between the devices, etc., as discussed in [149], [150], [151], and [152].

C. PRIVACY AND DATA SECURITY

Several companies like [151], [152] collect and handle data from current users for profiting from big data of personal information. Data breaches occur on an irregular basis at these MNCs. Consequently, while building the metaverse, it is vital to consider user privacy, and physical and psychological safety, especially in the healthcare sector. Metaverse records not just users' email addresses and passwords but also their activities [146]. With so many connected devices and people, the metaverse is guaranteed to have severe security problems. The technology stack of the health metaverse also highlights the dangers and complexity of sustaining a non-hackable system. Such risks jeopardize the uniqueness of a doctor-patient relationship. The topic of how to prevent this situation in the future must be investigated [153], [154].

D. IDENTITY HACKING

It is seldom sure if an online friend is as engaging in person as on social media. Similar questions will be raised in the case of the metaverse since users would access the metaverse through their avatars. Establishing your identity in the metaverse is difficult since bots may easily mimic your style, data, personality, and whole identity. Various validation procedures will be required for authentication, such as face scans, retina scans, and speech recognition [146], [155]. In the metaverse, it will be possible to build virtual duplicates of humans who act and exhibit personality features similar to real people. The creation of such "copies" is likely to result in various illicit purposes, including disseminating false news, purposeful mistaken identification, identity theft, and body swapping. XR might be utilized as a platform where individuals are seen to carry out immoral behaviors, thus poorly harming their social reputation. In XR, crackers may hack a person's avatar, and private information or security concerns can be exchanged while in virtual space with someone else [138].

E. ADDICTION AND MENTAL HEALTH

Metaverse allows users to hang out with new avatar friends and attend virtual shows, distancing themselves from in-person social life. Addiction to the virtual world may lead to weight gain, cardiac problems due to a sedentary lifestyle, and mental health concerns such as sadness and anxiety [146], [156], [157]. Ready Player One, a film representing the notion of the metaverse, has shown how metaverse technology might damage one's mental health [151]. Because people may witness highly realistic virtual situations from ads, television, gambling, and other sources while immersed in a fully immersive virtual environment for an extended time, the metaverse tends to increase people's propensity to abandon reality. Excessive use of digital technology leads to a range of mental health problems among users, including physical symptoms, sadness, paranoid thinking, and significant mental illness. Because of technology improvements, it is projected that people who are more engaged in the metaverse may face increasing social isolation, suicide, mental health issues, poor physical health due to bodily neglect, a desire to emulate other behaviors, and so on [158], [159].

F. CURRENCY AND DIGITAL PAYMENTS

Metaverse will be much more than a gaming platform. It will be an additional global online marketplace with billions of users. With so many currencies and cryptocurrencies, there will be a desire for speedy and frictionless trading, raising questions on the security of the transactions made in the metaverse [146], [160].

G. LAW AND JURISDICTION

With virtual crimes already being recorded on social media, the metaverse will have its fair share of lawbreakers. Blocking an account with rules and regulations will not be sufficient; instead, the correct laws are required for proper justice. However, the metaverse will not exist in physical space. Governments and agencies must decide their authority to create a secure virtual environment for users beyond international borders [146].

XII. CONCLUSION

In this work, we showed how the metaverse might be utilized in the future to modify, improve, and potentially revolutionize healthcare. This article discusses healthcare-related topics such as education, clinical treatment, physical fitness, mental wellness, etc. Our virtual-worlds (or digital twins) will seem fundamentally different in the future due to the incorporation of developing technology and the ongoing expansion and refinement of the ecosystem. As a result of the availability of powerful computing devices and intelligent wearables, our digitalized future will be more interactive, more living, more embodied, and more multimodal. However, other obstacles must be overcome before the metaverse can be fully integrated into our physical environment and daily lives. We advocate for a comprehensive approach to constructing the metaverse since we believe it will exist as a massively parallel world to our own. We aim to have stimulated a broader conversation within the metaverse community by reviewing the most recent works across diverse technologies and ecosystems in the healthcare business. We provide the essential framework for shaping the future of the metaverse in the coming decades by reflecting on the key topics we discussed.

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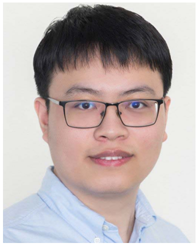

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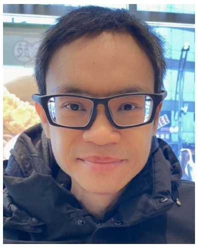

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