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Immersive Technologies in Healthcare

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ABSTRACT

Different forms of immersive technology, such as virtual reality (VR) and augmented reality (AR), are getting increasingly invested in healthcare. Immersive technologies are rapidly gaining traction in healthcare, offering transformative opportunities for patient care, medical education, and therapeutic interventions. They hold considerable promise in revolutionizing healthcare practices. The benefits of immersive technologies are vast and expanding, from enhancing healthcare and education, to strengthening collaboration and productivity. Immersive technologies also present powerful tools for visualization, communication, and collaboration in the medical profession. This paper aims at exploring the current applications of immersive technologies in healthcare.

KEYWORDS: *virtual reality (VR), augmented reality (AR), mixed reality (MR), extended reality (XR), assisted reality (aR), immersive technologies, healthcare, medicine, immersive technologies in healthcare, medical training.*

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INTRODUCTION

The world needs healthcare professionals to ensure the health of the community. Healthcare is a well-funded industry that is first on the line to adopt new technological innovations. The field of life sciences and healthcare sector have always benefited from various digital innovations. It is evident that immersive tools have made their way to the healthcare industry, revolutionizing many aspects of it. Implementing these tolls in healthcare is the breakthrough of the century.

Immersive technologies have rapidly grown in the recent decade, presenting the capability of seamlessly merging the virtual and physical realms. Immersive technologies such as VR, AR, and MR provide a full immersive experience by blending real and virtual worlds. Currently, immersive technologies are used in almost all fields with the convergence of other relevant technologies. The role of these immersive technologies is inevitable in the healthcare sector as well. Without much technical support, healthcare professionals and healthcare personnel can use these technologies. The impact of immersive technologies on health professions education has become a subject of significant interest. Figure 1 shows a representation of immersive technology [1].

WHAT ARE IMMERSIVE TECHNOLOGIES?

Immersive technology is any technology that extends reality or creates a new reality by leveraging the 360 space. Virtual reality (VR), augmented reality (AR), mixed reality (MR), extended reality (XR), and assisted reality (aR) are the most popular, principal types of immersive technologies. Therefore, we will consider only five types of digital realities leading to different types of immersive technologies.

1. *VIRTUAL REALITY:* VR, as implied by its name, involves the use of a specialized headset to simulate an environment in which the user is fully immersed. Virtual reality (VR) is XR at its most extreme. It completely immerses the user in a digital world, often using a computer-generated environment with scenes and objects that appear to be real. The term "virtual reality" essentially means "near-reality." Virtual reality is the key technology for experiencing sensations of sight, hearing, and touch of the past, present, and future. VR is a fully immersive technology where users

wear a head-mounted display and experience a simulated world of imagery and sounds. The terms, "virtual reality" and "cyberspace" are often used interchangeably. A cyberspace may be regarded as a networked virtual reality. A person using virtual reality can look around an artificial world, move around it, and interact with virtual features or items. This effect is commonly created by virtual reality headsets [2]. Virtual reality technology includes multiple components divided into two main groups: hardware and software components. The most common hardwire is the head-mounted displays (HMDs), which is used in combination with tracking systems. A head-mounted display is shown in Figure 2 [3].

2. *AUGMENTED REALITY:* Augmented reality (AR) is a technology that combines real-world environments with computer-generated generated information such as images, text, videos, animations, and sound. It can record and analyze the environment in real-time. In augmented reality, the user typically experiences the real world through a device such as a smartphone, tablet, smart glasses, or head-mounted display. For example, AR allows consumers to visualize a product in more detail before they purchase it. This feature enhances consumer interaction and helps them never to repurchase the wrong item. The key objective of AR is to bring computer-generated objects into the real world and allows the user only to see them. In other words, we use AR to track the position and orientation of the user's head to enhance/augment their perception of the world. Augmented reality falls into two categories: 2D information overlays and 3D presentations, like those used with games [4].
3. *MIXED REALITY:* Augmented reality and virtual reality often go hand in hand in many applications, constituting what is known as mixed reality or hybrid reality. Mixed reality (MR) is a term used to describe the merging of a real-world environment and a computer-generated one. Physical and virtual objects may co-exist in mixed reality environments and interact in real time. This is an extension of AR that allows real and virtual elements to interact in an environment. MR liberates us from screen-bound experiences by offering instinctual interactions with data in our living spaces and with our friends. Online explorers, in hundreds of millions around the world, have experienced mixed reality through their handheld devices [5].
4. *ASSISTED REALITY:* Like mixed reality, assisted reality (aR) is an extension of augmented reality, with a few notable differences to both. One of these differences is that aR is primarily hands-free through the wearing of a headset, whereas AR usually requires the holding of a device such as a mobile phone. While MR is a digital-first, real-world second reality, aR is a real-world first system. It combines software and a head-mounted display. It is best experienced using smart glasses or other wearable technology.
5. *EXTENDED REALITY:* The term "extended reality" (XR) has recently gained favor as an umbrella term that encompasses all of AR, VR, and MR. The primary user inputs for XR devices are described as follows. Voice interfaces are now ubiquitous thanks to mobile devices and standalone smart speakers. Many XR devices enable user control with handheld controllers, which have capabilities beyond button press inputs. Both voice-driven interfaces and human-computer interactions have been developed specifically for XR devices, including gaze and gesture controls [6]. Extended reality (XR) is the overarching term used to describe employing technology to blend real life and the digital world. It includes all the machine-human interfaces beyond the physical realm (reality) such as augmented reality (AR), mixed reality (MR), assisted reality (aR), and virtual reality (VR). Figure 3 shows the XR spectrum [7].

IMMERSIVE TECHNOLOGIES IN HEALTHCARE

Immersive technologies refer to a category of digital technologies that aim to immerse users in a simulated or augmented environment. The healthcare industry has been exploring the potential of immersive technologies since the early 1990s, when surgical training simulators became the first successful commercial application of VR. The rising stress in public health systems has created a demand for assistance systems, which is one of the reasons for the rapid development of AR and VR.

Although AR/VR gaming is currently the largest force driving the adoption of immersive technologies, healthcare applications have rivaled gaming for greatest economic impact in the industry. Immersive technologies enhance traditional methods of healthcare and present new treatments to explore. They empower doctors to be more accurate, patient centered, and efficient in a health-care landscape with more patients than ever. AR/VR is already playing a large role in medical education. In architectural practice, XR is being increasingly used for the design and development of healthcare facilities [8]. A typical use of immersive technology in healthcare is depicted in Figure 4 [9].

APPLICATIONS OF IMMERSIVE TECHNOLOGIES IN HEALTHCARE

In the rapidly evolving healthcare field, immersive technologies are ushering in a new era of patient care and medical training. A broad range of applications of immersive tech are transforming how healthcare industry operates, optimizes, and creates value for society. Some of the roles of immersive technology in healthcare are shown in Figure 5 [10]. Common applications of immersive technologies in healthcare include the following [8,11,12]:

- *Student Education:* Immersive technology serves as an effective teaching tool. Arguably one of the largest use cases for AR/VR in healthcare today is for medical student training. Practicing procedures in a high quality virtual environment provides a risk-free way for learning new techniques. Students can witness the results of mistakes without real-life consequences. Virtual procedures can also lower educational costs by eliminating the need for physical resources. For decades, junior doctors have primarily learned surgical skills through direct experience in the operating room under the supervision of seasoned surgeons. VR simulations provide a highly realistic and interactive learning environment, surpassing traditional methods. In medical training, the future of VR and AR lies in their potential to revolutionize surgical education, allowing trainees to practice complex procedures in a risk-free environment. Because innovations in medicine are constant, doctors and practitioners need refresher courses and training to learn new techniques and treatments, even after graduating from medical school. The educational application of immersive technology can be categorized into academic education, surgical training, and clinical training. Figure 6 shows a typical VR training simulation [13].
- *Patient Education:* Patient education is a cornerstone of effective healthcare, and XR technology acts as a bridge between medical professionals and patients. Consumer-level virtual applications can empower patients to learn about their conditions, accurately describe symptoms, and explore treatments and facilities from the safety and comfort of their own homes. One of the most promising use of VR/AR technology was inviting cancer patients to use a combination of VR and AR to explore treatment and recovery facilities from home. This increased patient confidence, decreased anxiety about treatment, and resulted in more patients reporting a positive experience. For example, Stanford University's "virtual heart" uses immersive VR to educate medical students, families, and patients about heart defects.
- *Medical Research:* The COVID-19 pandemic has led to more people experiencing mental health issues and contributed to the immense pressure on mental health support services. One emerging field that holds promise for transforming mental health provision is immersive technology, which can be used to visualize complex medical data, such as MRI or CT scans, in a more intuitive way. This can help researchers identify patterns and relationships that may not be immediately apparent in traditional 2D representations. Emerging technologies such as AI and AR/VR can help provide a better understanding of the underlying biology of diseases by allowing researchers to better model and visualize complex molecular structures. Researchers are also using AR/VR to improve the development and trial process of pharmaceutical drugs and medical devices.
- *Rehabilitation:* Immersive technology is showing great promise in rehabilitation, particularly for stroke patients. VR app turns rehabilitation exercises into a motivating, gamified experience for patients. VR games help patients to relearn motor skills in a fun, novel environment. Immersive technologies are also showing promise for rehabilitation for neurological and cognitive conditions, as well as in physical therapy. VR rehabilitation for physical and occupational therapy includes helping patients retrain motor functions, practice coordination, and simulate real-world tasks. There is also great potential for using AR/VR for rehabilitation following traumatic brain injuries and neurodegenerative diseases. VR is being increasingly utilized for physical and neurorehabilitation, especially for home-based rehabilitation.
- *Radiology:* VR provides immersive 3D experiences for radiologists. VR in radiology offers users an immersive 3D experience through wearable technology. Technology aims to enhance medical imaging accessibility and collaboration among radiologists. Immersive technology may have a promising future in cardiology.
- *Telemedicine:* AR/VR may provide new and improved avenues for telemedicine. While videoconferencing appointments today allow patients to meet with their doctor without having to physically travel to see them, AR/VR can allow patients to feel like their doctor is in the room

with them, leading to highly realistic appointments. AR can be particularly beneficial for telemedicine, remote assistance, and patient evaluation. VR integrates into surgical education, allowing realistic simulations and objective performance assessments. Immersive 3D environments aid in anatomy learning and clinical experience for students. Immersive technology can create a realistic experience that may improve the quality of communication and diagnosis during telemedicine sessions.

- *Diagnoses:* A diagnosis of mental illness is rarely simple and straightforward. Providing an accurate diagnosis is a crucial yet difficult part of healthcare practitioners' jobs. VR and AR technologies enhance diagnostics by providing immersive and interactive environments for examining patient data. AR/VR has the potential to assist doctors in making accurate diagnoses through enhanced medical imaging and visualizations and better global collaboration with other specialists. A wide range of practitioners can benefit from using AR/VR to better make diagnoses, including dermatologists identifying skin conditions, cardiologists finding structural issues within the heart, and oncologists visualizing tumors more accurately to help treat cancer.
- *Oncology:* VR has been used to help reduce anxiety and pain in cancer patients through distraction in a variety of situations, including during chemotherapy, palliative and supportive care, and for patients undergoing painful medical procedures.
- *Cardiology:* Cardiologists deal with life-threatening conditions daily and perform complex percutaneous interventions. Solid lifelong training and efficient communication under stress are required to reduce the risk of complications and improve the outcome. Immersive technology has provided additional opportunities to traditional cardiologist training methods by reducing the risk associated with apprenticeship methods. By using immersive technologies during a procedure, the sensors information can be mapped on a virtual display. Three key application areas for immersive technology in cardiology are: (1) education and training, (2) diagnostic and telemedicine, and (3) surgical applications. Figure 7 shows main applications of immersive technology in cardiology [14]. Immersive technology may have a promising future in cardiology.
- *Mental Health:* Mental health treatments have become the number one concern all over the world. And with the help of AR and VR tech, it is revolutionizing and creating immersive environments for therapy. For example, patients can explore calming virtual worlds, practice coping strategies in a controlled setting, mediate on the sea beach, etc. This approach helps reduce anxiety and manage stress. Virtual reality is used in controlled exposure therapies, relaxation techniques, concentration, and stress reduction.
- *Pediatric Health:* Immersive experiences must be created to ensure that they are developmentally appropriate and engaging for children of different ages. Comfortable devices must be used that minimize discomfort and ensure a positive experience for young patients during therapy sessions or medical procedures. Parents must be fully informed about the purpose, risks, and benefits of using AR/VR in their child's healthcare. Figure 8 shows a child's use of immersive technology [15].
- *Surgical Settings:* In surgical settings, XR technology assumes a pivotal role in both preoperative planning and intraoperative navigation. Surgeons can walk inside a patient's anatomy, be it a brain, heart, or spine, to better plan for an operation and create superior outcomes for patients. They can overlay critical information directly onto a patient's anatomy, providing precise guidance during complex procedures. This not only minimizes risks associated with surgeries but also contributes to shorter recovery times and improved overall patient outcomes. The precision afforded by XR-enhanced surgical planning is unparalleled. The real-time navigation capabilities during surgery further empower surgeons to make informed decisions, ensuring optimal outcomes for patients. AR provides surgeons with "X-ray vision" by fusing digitally enhanced images directly overlaid on the surgeon's field of vision to aid intervention. Patients can go on a visual journey that helps them understand and experience their surgery like never before and make an informed decision about their health. A typical use of immersive technology in surgery is displayed in Figure 9 [13].

BENEFITS

Immersive technologies provide novel, cost effective solutions in healthcare. They are helping practitioners take healthcare to the next level in a number of areas, particularly education and mental health treatment. Extended reality technologies offer numerous

advantages for healthcare applications, whether used alone or alongside traditional technologies. Immersive technologies enhance traditional methods of healthcare and present new treatment options to explore, ultimately saving money and producing better outcomes for patient health. Other benefits include the following [13,16]:

- *Cost Effectiveness*: AR/VR for training purposes is the more cost-effective option over traditional training programs. Immersive technologies could enable multiple repetitions of simple tasks in a clinical setting within an immersive environment, reducing the need for constant supervision by the medical staff, which could significantly lower the costs associated with training facilities. XR enables the quality of care by lowering the physical impact on the patient, shortening their recovery time, and therefore resulting in significant healthcare savings. The cost of immersive tools is usually less than the cost of the actual physical medical equipment itself.
- *Enhancing Training:* VR and AR tools offers a safe, controlled, immersive environment for learning, allowing medical students to obtain vital skills in the simulation without cutting into patient skin and risking their lives. Introducing VR into the medical education process can optimize learning, from boosting anatomy knowledge to improving medical social skills. VR software offers surgeons a risk-free space to perform fake surgeries and develop practical skills.
- *Safe Environment:* One of the benefits of medical training using immersive technology is that it provides a safe environment to learn and train. VR technology changes the way of practical medical training, providing a safe environment for practitioners to acquire hands-on skills. Across the world, people have been pushed out of the offices, the classrooms, and into their own homes in the name of safety, a duty of responsible behavior toward others. Immersive technology allows students to practice utilizing simulations on a host of healthcare issues with different people and teams.
- *Accessibility:* Access to technology is a prerequisite for all things concerning development. By learning and practicing in the digital realm, more people can access the learning content and get trained in the procedures and processes required. VR and AR are used to provide remote consultation, physical therapy, and rehabilitation through gadgets like Google Glass, VR apps, and other handheld devices, reducing the need for in-person visits and travel costs.
- *Personalization:* Immersive technology may be personalized. It may be set up to respond both to the users' personal manipulations and the medical training instructor to accentuate learning in areas where the student may require more attention and focus. It will also provide instructors with the ability to tailor the content fed to the student and respond to their queries. Its convenience allows for self-paced customized training.
- *Patient Satisfaction:* AR and VR apps enhance the patient's experience by providing simulation and visualization of further medical procedures or treatments. It can reduce the stress patients are going through and act like a pain management tool. AR and VR in healthcare elevate medical treatment and help practitioners deliver outstanding patient care.
- *Engagement:* Immersive technologies intensely capture one's attention and focus in a way that other mediums cannot. They are an especially effective tool for learning by simulating unique or challenging situations. The learning possibilities are endless. Research has shown that utilizing immersive technology results in far better retention and lasting impact.
- *Distraction:* VR devices can distract attention away from unpleasant stimuli such as pain, or traumatic thoughts, or fears, allowing a patient to spend time immersed in more pleasant activities, perhaps watching a sunset, or sitting on a tropical beach. Patients frequently perceive the hospital as an "unfriendly" environment because of several factors such as overwhelming noise, loss of personal autonomy, and insufficient information. To reduce the attention available for conscious processing of stress and anxiety, VR is often used to provide straightforward distractions, for example, watching videos or playing video games. This approach shifts the patient's focus away from conscious awareness of stressful situations during occupational activity.

CHALLENGES

In spite of their potential, there are challenges to implementing immersive tech in healthcare. One of the primary challenges is ensuring that immersive tech hardware is seamlessly integrated into existing healthcare systems. Some key challenges include integration issues, classification ambiguities, and regulatory burdens. AR/VR innovation needs to accelerate in order to meet the critical demands of healthcare. It is important to note that AR/VR

treatments are not useful for all patients. Other challenges include the following [8,11]:

- *Cybersickness*: Prolonged use of VR can lead to side effects such as headaches, nausea, and vomiting—commonly referred to as "cybersickness"—which are similar to symptoms of motion sickness. While motion sickness arises from a discrepancy between actual and expected motion, this pathophysiological mechanism may not fully apply to cybersickness. Interestingly, cybersickness may be more pronounced in AR than in VR.
- *Regulations:* The health-care industry is heavily regulated in the United States by the Food and Drug Administration (FDA). Recent updates by FDA have paved the way for more widespread use of immersive technologies like VR and AR in healthcare. The United States has a multitude of federal and state privacy laws to address specific risks. The ultimate goal should be to maximize the benefits of immersive technologies in healthcare while minimizing the risks through well-crafted, targeted regulations. To ensure interoperability and cohesive integration of XR into medical practices, standardization efforts are crucial.
- *Risks:* Despite the many benefits and use cases of XR in healthcare, there are certain risks policymakers should consider. The ultimate goal should be to maximize the benefits of immersive technologies in healthcare while minimizing the risks through well-crafted, targeted regulations.
- *Privacy:* Many AR/VR applications present unique privacy concerns. These technologies collect large volumes of sensitive personal data, including data from users interacting with virtual environments. Much of the information that AR/VR devices collect is sensitive data not used as often in other consumer technology devices—yet it is critical to the core functions of AR/VR.
- *Security:* Hospitals and healthcare institutions are at high risk of cyberattacks, which results in liability concerns, privacy violations, reputational damage, and technical challenges for these institutions.

CONCLUSION

As technology continues to advance in the healthcare sector, immersive technology is becoming increasingly popular in healthcare settings for diagnostic and therapeutic purposes. VR has become a game-changing tool in healthcare services, offering an improved patient experience, better medical training, and innovative therapeutic interventions. As AR/VR demonstrates clinical utility, the health-care industry stands well poised to alter the public health system, leading to better health outcomes for all Americans. As immersive technology has become more advanced with time, it has had an increasing role in healthcare. The potential benefits overshadow the challenges, encouraging hospitals and healthcare providers to delve deeper into the realm of immersive technology.

Immersive technologies are playing an increasingly crucial role in revolutionizing health professions education, as they provide students with realistic and interactive learning experiences. They are ushering in a new era of patient care and medical training. From redesigning surgical training to enabling remote assessment to assisted rehabilitation techniques, immersive technology is gaining momentum to reshape health industry, globally. In order for immersive technologies to be a standard part of healthcare, efforts are needed to upskill healthcare professionals, patients and caregivers. Immersive technology is going to play a large role in the future of healthcare, there is no denying this. More information about immersive technologies in healthcare can be found in the books in [17-23].

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Figure 1 A representation of immersive technology [1].

Figure 2 A head-mounted display [3].

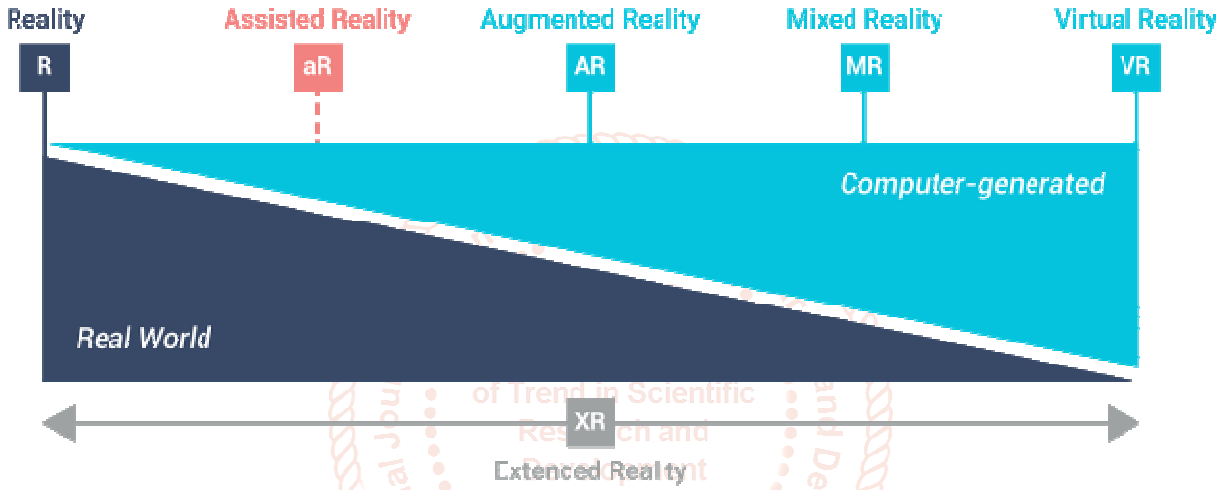

Figure 3 The XR spectrum [7].

Figure 4 A typical use of immersive technology in healthcare [9].

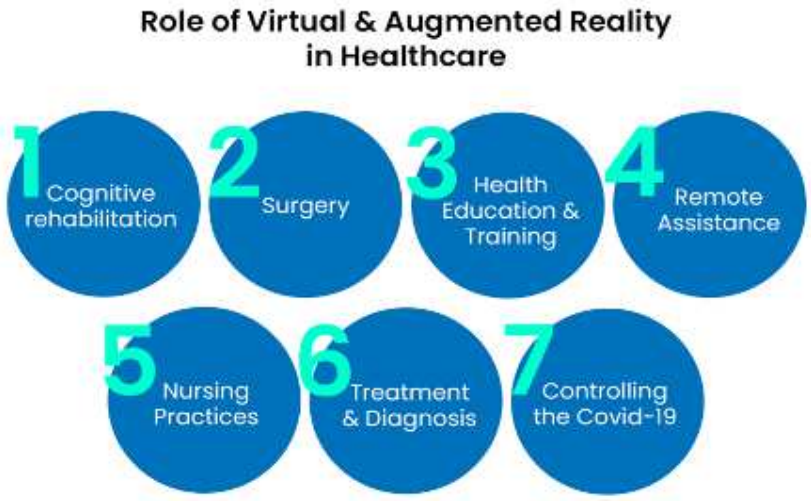

Figure 5 Some of the roles of immersive technology in healthcare [10].

Figure 6 A typical VR training simulation [13].

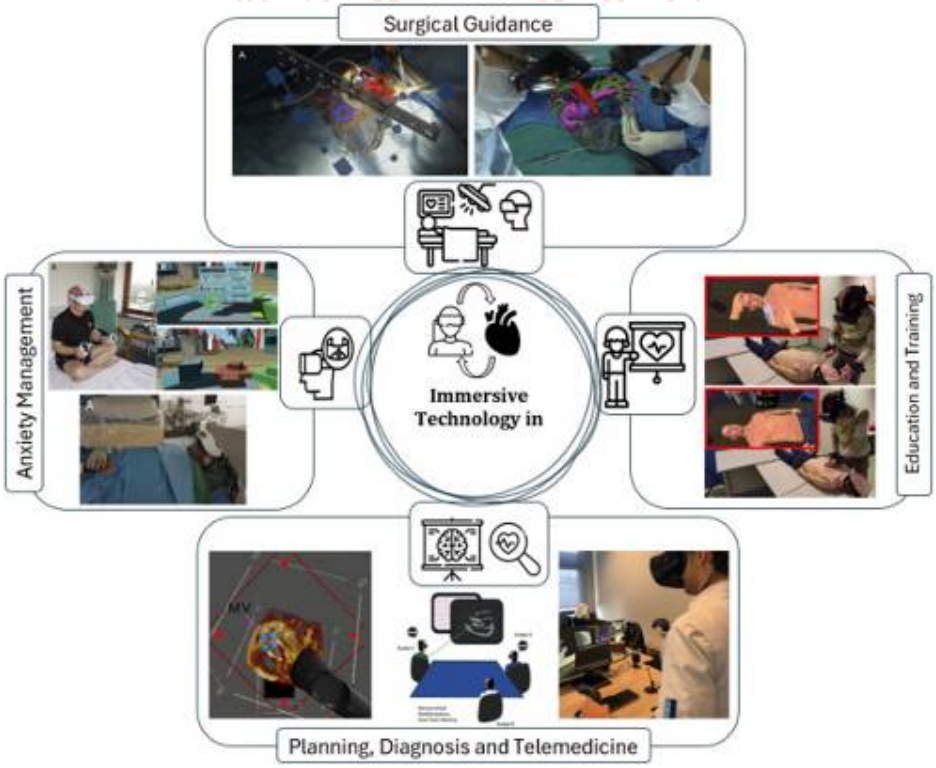

Figure 7 Main applications of immersive technology in cardiology [14].

Figure 8 A child's use of immersive technology [15].

Figure 9 A typical use of immersive technology in surgery [13].