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# INTEGRATING VR/AR INTO ROBOTIC SURGERY EDUCATION: A MODEL TO ENHANCE UPTAKE IN SAUDI HOSPITALS

## *INTEGRAÇÃO DE RV/RA NA EDUCAÇÃO EM CIRURGIA ROBÓTICA: UM MODELO PARA AUMENTAR A ADOÇÃO EM HOSPITAIS DA ARÁBIA SAUDITA*

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**Abstract**

There has been a sustained effort to highlight the potential of immersive technologies, such as XR, VR, and AR, to enhance surgical precision and improve accessibility in health and biotechnology from 2020 to 2025. In accordance with the PRISMA guidelines, 276 documents were retrieved from Web of Science (WoS), and 50 research articles were ultimately included in the study. Despite hard work in a new era of healthcare with even greater potential, further research is required to elucidate the future challenges and opportunities that lie ahead. Adequate health literacy is a significant challenge because it influences relationships between patients and doctors, access, and self-management, all of which are essential for improved health outcomes. The study also identifies recent changes in medical education in a rapidly changing healthcare environment. It then performs a systematic review of current healthcare and training applications of virtual, augmented, and extended reality targeted at improving knowledge, skills, and user engagement. Furthermore, it analyzes how 6 G technologies can support low-latency m-health and VR/AR services and discusses the use of wearables and exoskeletons to minimize ergonomic risks. This work synthesizes the benefits and limitations of immersive technologies, proposes an integrative framework that links 6G, XR, and wearables for safe, practical training and care, and outlines future research directions, particularly for resource-poor settings.

**Keywords:** Robotic Surgery. Virtual Reality. Augmented Reality. Surgical Simulation. Saudi Arabia. Scfhs. Medical Education. Competency-Based Training.

***Resumo***

*Houve um esforço contínuo para destacar o potencial das tecnologias imersivas, como XR, VR e AR, para aumentar a precisão cirúrgica e melhorar a acessibilidade na saúde e na biotecnologia de 2020 a 2025. De acordo com as diretrizes PRISMA, 276 documentos foram recuperados da Web of Science (WoS) e 50 artigos de pesquisa foram incluídos no estudo.*

*Apesar do trabalho árduo em uma nova era da saúde com potencial ainda maior, são necessárias mais pesquisas para elucidar os desafios e oportunidades futuros que estão por vir. A alfabetização adequada em saúde é um desafio significativo, pois influencia as relações entre pacientes e médicos, o acesso e o autocontrole, todos essenciais para melhores resultados de saúde. O estudo também identifica mudanças recentes na educação médica em um ambiente de saúde em rápida transformação. Em seguida, realiza uma revisão sistemática das aplicações atuais de saúde e treinamento de realidade virtual, aumentada e estendida, com o objetivo de melhorar o conhecimento, as habilidades e o envolvimento do usuário. Além disso, analisa como as tecnologias 6G podem oferecer suporte a serviços de saúde móvel e VR/AR de baixa latência e discute o uso de dispositivos vestíveis e exoesqueletos para minimizar os riscos ergonômicos. Este trabalho sintetiza os benefícios e as limitações das tecnologias imersivas, propõe uma estrutura integrativa que conecta 6G, XR e dispositivos vestíveis para treinamento e cuidados seguros e práticos e descreve as direções futuras da pesquisa, especialmente para ambientes com poucos recursos.*

***Palavras-chave:*** *Cirurgia Robótica. Realidade Virtual. Realidade Aumentada. Simulação Cirúrgica. Arábia Saudita. Scfhs. Educação*

*Médica. Treinamento Baseado em Competências.*

## 1 INTRODUCTION

Augmented reality (AR) is a technology that layers digital content onto the user's real-world environment, creating an enriched view of physical surroundings. It represents a significant shift in how medical care and education are delivered (Faizan Siddiqui et al., 2025). In practice, AR supports surgical planning and patient care and helps patients better understand complex medical conditions. AR applications are now visible in many areas of medicine, and the growing strain on public health systems—particularly during pandemics—has increased the demand for such supportive tools. In parallel, the use of virtual reality (VR) and AR in fields such as surgery, dentistry, telemedicine, self-care, and wellness has already contributed to meaningful improvements in various aspects of healthcare (Charlet, M. 2025). The incorporation of AR offers numerous opportunities to improve surgical accuracy, enhance patient involvement, and tailor medical care to individual needs. When AR is used alongside technologies such as virtual reality (VR), artificial intelligence (AI), and robotics, it unlocks additional pathways for innovation in clinical practice, education, and skills development (Lastrucci, Andrea, et al 2024). There has been increased access to commercially available, rather than research-oriented, virtual reality (VR)/augmented reality (AR) headsets, driven by advances in sophistication (Lin, Ping-Yi, et al 2024).

Interactions with virtual environments are no longer constrained to joysticks, keyboards, and other handheld devices; they have expanded to include body-tracking systems that capture full-body motion. The miniaturization of hardware, graphics, and sensors has increased the portability, realism, and user-friendliness of VR and AR systems (Kyriakou et al., 20254). The latest systems typically use a combination of visual, auditory, and haptic/olfactory inputs, thereby providing a broader range of highly realistic experiences. Against this broader technological backdrop, VR has attracted considerable interest in healthcare (Opoku-Baah, Collins, et al. 2021). Generally, it consists of a head-mounted device that covers the user's entire visual field, creating a computer-generated three-dimensional environment. In this way, it provides the user with a sense of physical presence in a virtual environment that can handle complex interactions with computer-generated elements or agents. The agents, called "avatars," can be programmed to respond to user input, thereby providing a more profound sense of engagement (Wang, Yuying, et al., 2025). AR, although closely linked to VR, works by projecting graphical objects or data layers onto a real-time image of the real environment, typically via a camera feed to a head-mounted display or a portable device (Felton et al 2022). This convergence of tactile, auditory, and visual inputs enables users to manipulate computer-generated objects while remaining cognizant of the real-world setting. AR, although closely linked to VR, projects graphical objects or data layers onto a real-time image of the real environment, typically via a camera feed to a head-mounted display or a portable device (Sheng, Ting 2020). This convergence of tactile, auditory, and visual inputs enables users to manipulate computer-generated objects while remaining cognizant of the real-world setting. At the same time, these advances are accompanied by many unresolved questions and research areas that still require careful investigation (Bhowmik, Achintya K, 2024)

## 2 LITERATURE REVIEW

### 2.1 Based on PRISMA-guided and related studies on VR/AR in health professions education

In a systematic review, Siddiqui et al. (2025) examined the current use of extended reality (XR), including VR and AR, in healthcare practice and education. The systematic review aims to synthesize empirical evidence and review the literature on surgical education, preoperative planning, emergency simulation, patient education, and telemedicine. The aim is to chart the use of XR, discuss its benefits in education and healthcare, and identify areas requiring further development, particularly in low- and middle-income countries (LMICs). The authors concluded that XR has the potential to increase surgical accuracy, enhance anatomical demonstration, and facilitate the rehearsal of complex surgeries without risk, and that XR has enormous potential to improve educational and healthcare practices. Additionally, most of the literature is from high-income countries; literature from LMICs is limited, and challenges related to accessibility, cost-effectiveness, and scaling up remain inadequately addressed.

In this review, several reviews following PRISMA guidelines are briefly described that specifically relate to education in medicine/surgery. Jiang et al. (2022)

conducted a scoping review following PRISMA-ScR guidelines to describe the use of VR in undergraduate medical education. The design involved identifying 114 studies on the use of VR in surgery simulators, 3D models, or virtual worlds. The aim is to determine which VR modality is most commonly used, as well as the levels of immersion and interactivity employed. The findings indicate that most are linked to surgery (60.5%) and anatomy (13.2%), with a predominant use of semi-immersive VR and highly interactive systems, which are less commonly used for non-psychomotor skills, such as communication and teamwork. New technologies, such as mobile VR and virtual dissection tables, remain rare. This study also concluded that most findings are from high-income countries and that theoretical frameworks are rarely used.

This is supported by a systematic review and meta-analysis by García-Robles et al. (2024), as summarized by Siddiqui et al. The research investigated the application of immersive VR and AR technologies in anatomy learning. This research design combined 27 primary studies, involving a total of 2,199 health science students, that compared the implementation of XR technologies with conventional methods such as textbooks and lectures. The findings showed a positive impact of XR on knowledge, with a standard mean difference of approximately 0.40, with greater benefits when XR is used as a supplement to, rather than an entirely replacement for, existing teaching methods. About 80% of the population thought that XR application is practical, with the most benefited group being university-level students. The drawbacks of this research included the lack of standardization of the XR technologies used, the potential for publication bias, and the underrepresentation of LMICs.

In a mixed-methods literature review, Li et al. (2024) examined the use of VR and AR in medical education, particularly in low- and middle-income countries. This design employed a mixed-methods approach comprising a systematic synthesis of findings from 17 empirical VR/AR studies involving 887 participants and a survey of 35 medical students in Egypt and Ghana. The goals of this literature review were to examine the effectiveness of VR/AR use in LMICs for medical education, to explore priority areas for application, and to reflect on real-world constraints that affect the accessibility of VR/AR. Most contemporary applications of VR/AR in LMICs are directed toward surgical practice, particularly general surgery, with a documented preference for VR/AR over a 2D educational approach.

In addition to the work specifically focused on LMICs, other reviews synthesised in Siddiqui et al.'s article contribute to the existing literature on immersive technologies in healthcare education. For instance, Arjomandi Rad et al. (2021), in a systematic review of XR in thoracic surgery, assessed 21 reviews published from 2007 to 2019. The review aimed to synthesise the use of XR in patient training, preoperative planning, and intraoperative navigation. The findings revealed that 3D XR models significantly improved accuracy, surgeon confidence, and preoperative planning for complex thoracic procedures. Although the findings are significant, the existing literature on XR in thoracic surgery is minimal, primarily from high-income countries, and yields inconclusive overall findings.

In addition to these systematic reviews, Ramachandram et al. (2025) conducted a qualitative exploratory study to assess practising pharmacists’ views on the use of VR and AR technologies in pharmacy education. This research targeted registered pharmacists from hospitals, communities, industry, and educational institutions in Malaysia, using purposive sampling to recruit potential participants who were still in the registration process but were considered pharmacists. The research employed a semi-structured interview technique, in which respondents were interviewed either in person or via online platforms. The authors reported that pharmacists considered AR/VR promising technologies for complex learning areas, such as drug design, pharmacotherapy, and patient engagement, and that they were associated with improved simulation, visualisation, and the repetition of safe practices. On the other hand, pharmacists expressed concerns regarding the realism of the system, the protection of private information, the recording of sensitive performance data, and the development of guidelines before implementation. The research concluded that the application of AR/VR technologies within pharmacy programs may support a future-oriented workforce, but requires consideration of infrastructure, ethics, and guidelines.

Taken together, these PRISMA-informed reviews and qualitative research papers clearly indicate a consistent theme: the use of immersive technologies to support surgical skills training, anatomy learning, emergency scenario simulation, and professional skills development across a variety of healthcare disciplines. Research designs range from systematic reviews that synthesise findings from several hundred studies to in-depth interviews that elicit professional perspectives. Across these research contributions, common findings indicate enhanced knowledge, skills, and engagement, as well as the identification of research gaps.

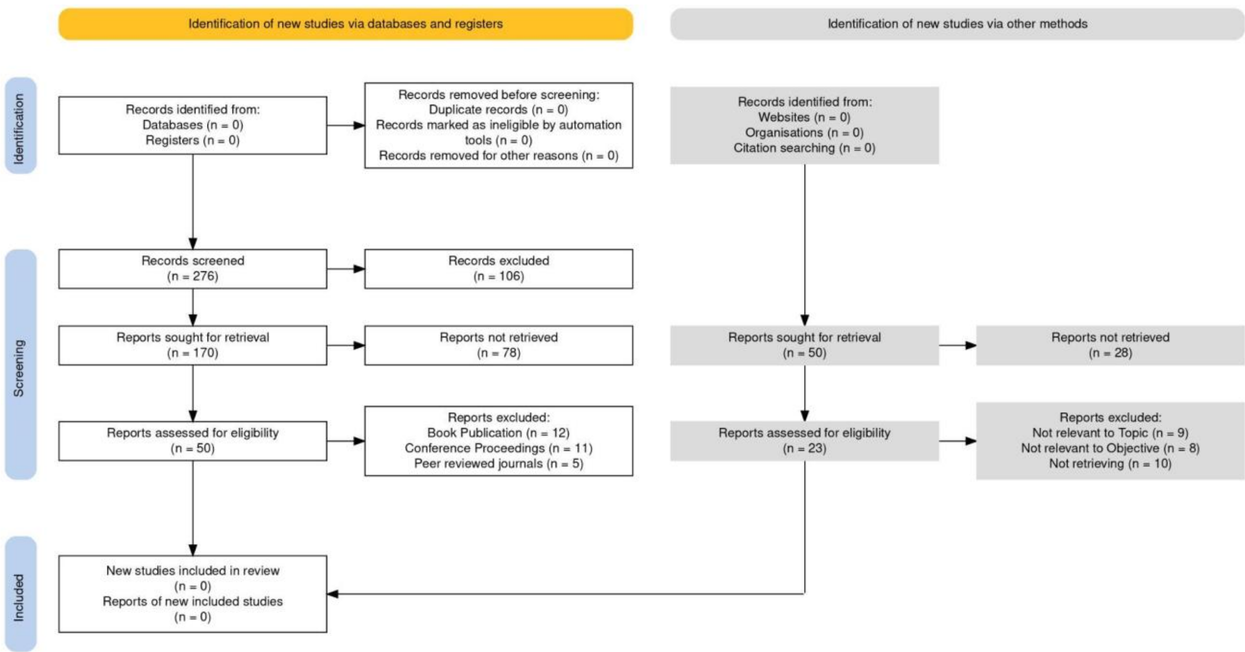
## 3 METHODOLOGY

### 3.1 Prisma framework in systematic review methodology

The systematic review aims to synthesize empirical evidence and review the literature on surgical education, preoperative planning, emergency simulation, patient education, and telemedicine. This will map the uses of XR; discuss its benefits in education and healthcare; and identify areas requiring further development, particularly in low- and middle-income countries. The authors conclude that XR could increase surgical accuracy, improve anatomical demonstration, and allow for the rehearsal of complex surgeries without risk. Furthermore, they argue that XR's potential to enhance educational and healthcare practices is substantial. Most of the literature comes from high-income countries, is scarce in LMICs, and poorly addresses accessibility, cost-effectiveness, and scaling up.

**Figure 1**

*Identification of new studies via databases and registers*



The use of a PRISMA flow diagram is critical to documenting the study flow throughout the literature review process. The flow diagram helps to divide the whole literature review process into four stages, which are:

In this systematic review, the PRISMA flow diagram indicates that 276 records were initially screened, of which 106 were excluded at the screening level. For the remaining records, 170 reports were sought for retrieval, with further exclusions based on full-text screening (e.g., book publications, conference proceedings, and non-related subjects or objectives), resulting in no studies being added.

### 3.2 Overall objective

To investigate how immersive and emerging digital technologies contribute to training, safety, and quality of experience in health and work-related environments.

### 3.3 Specific objectives

The objective is to undertake a systematic review of the existing uses of Virtual Reality, Augmented Reality, and Extended Reality in healthcare and to analyse how these can be harnessed to improve knowledge, skill levels, and end-user interaction.

1. To examine ways in which the most critical 6G-enabling technologies, including THz communications, mURLLC, AI, network slicing, RIS, and blockchain, may enable high-quality and low-latency m-health and telemedicine services, including those based on VR/AR.
2. To examine the efficacy of wearable sensors, extended reality technology, and exoskeleton and robotics in reducing ergonomic dangers and musculoskeletal disorders in high-risk environments.
3. To determine, based on literature, typical advantages and disadvantages which have been described in connection with immersive and emerging tech solutions, such as usability, level of reality, accessibility, infrastructure requirements, and concerns about privacy/ethics.

Based on these considerations, an integrated conceptual framework can be devised to integrate 6G connectivity with immersive technology solutions, such as Virtual

Reality/Augmented Reality/Mixed Reality, and ergonomic/clinical tools, such as wearables and exoskeletons, to enable safe and feasible training and service delivery.

The objective is to present future research and implementation directions in light of the identified gaps across the reviewed studies, in general, and in developing-country contexts, in particular.

Although there were no follow-up empirical studies, a logical sequence of patient selection begins with a rigorous set of predefined criteria.

Academically, PRISMA is a double-edged sword in the medical literature. On the one hand, it is a guideline for research reporting; most high-impact medical journals now require that systematic reviews include a PRISMA checklist and flow diagram at manuscript submission. As a consequence, this trend has improved the standard of describing methods, inclusion and exclusion criteria, and the search strategy in systematic reviews. On the other hand, PRISMA is used in the theoretical design of systematic reviews, where authors apply it not only for documentation but from the protocol stage onward, with a research strategy based on a checklist.

The updated PRISMA 2020 guidelines are fundamental in the current state of evidence synthesis. According to Page et al. (2021), the updated guideline considers advances in electronic search, bias assessment, meta-analytic methods, and methods for addressing heterogeneity. The updated PRISMA 2020 guideline provides explanations and examples of correct documentation for each checklist item to facilitate authors' understanding.

Apart from these core guidelines, several extensions have been produced to cover more specific kinds of systematic reviews or challenges in methodology, including PRISMA-P, which is for study protocols; PRISMA-ScR, which is for scoping reviews; PRISMA-NMA, which is for network meta-analyses; and PRISMA-S, which is for statements on searching. Taken collectively, these extensions illustrate a broad expansion of PRISMA from a single tool to a set of tools.

In your own research, including the phrase "was conducted and reported in accordance with the PRISMA 2020 guideline" in the abstract demonstrates adherence to global best practices. Use of the PRISMA flow diagram, along with metrics such as records screened, excluded, and assessed for eligibility, is essential for improving your research methodology. With this information, all readers, including editors, will have an idea of how you compiled your evidence base.

# 4 RESULTS AND DISCUSSIONS

## 4.1 Thorough review of augmented reality technologies – sensors

The analysis shows that substantial work in augmented reality has occurred across a variety of basic research domains, including tracking technology, display systems (VST/OST), authoring systems, collaborative augmented reality, interaction methods, guidelines for augmented reality, and security/privacy.

The result is that Augmented Reality has significant potential for application across sectors such as travel, education, and industry. Some of the most critical remaining issues include interfaces, tracking accuracy, hardware, and acceptance.

The authors strongly suggest that hybrid tracking solutions, including the integration of SLAM, inertial sensors, and GPS, as well as new display and interaction concepts, represent essential directions for enhancing robustness.

Areas in which future research is especially warranted include hybrid interfaces for augmented reality, evaluation, visualisation, support for authoring tools, and acceptance studies, as this area is evolving rapidly yet remains understudied.

## 4.2 The importance of 6G Technology in improving quality of experience in mHealth multimedia services

The study finds that small cell technology, terahertz bands, 3CLS, enhanced multimedia broadcast-multicast service, network slicing, AI, blockchain, Reconfigurable Intelligent Surfaces, Extended Radio, and mobile ultra-reliable low-latency communication have capabilities to support high-speed, reliable, and low-latency requirements of mobile healthcare communications (Nasralla, Moustafa M., et al 2023).

These technologies will enhance the Quality of Experience (QoE) in mobile healthcare multimedia applications, including telemedicine, remote diagnosis, and continuous patient monitoring.

The authors highlight that, in 6G-assisted telesurgery and surgical simulations conducted in virtual or augmented reality environments, mobile ultra-low-latency and terahertz communication can be used to support coherent communication with low latency and secure control signals for robotic systems. The integration of blockchain technology with unmanned aerial vehicles enhances the security of telesurgery.

In light of the above analysis, it can be concluded that, based on the findings of this survey, the integration of Artificial Intelligence, Blockchain, Reconfigurable Intelligent Surfaces, and Internet of Bio-Nano Things/Internet of Things in the architecture of 6th Generation technology will have a critical role in shaping future intelligent healthcare networks.

### 4.3 Review of emerging technologies for reducing ergonomic hazards in construction workplaces –buildings

In this review, the article identifies three categories of emerging technologies necessary to mitigate ergonomic hazards and nonfatal musculoskeletal injuries in construction work: wearable sensor technology, extended reality (virtual, augmented, and mixed reality) technology, and exoskeleton/robotic technology.

Wearable sensors, including inertial measurement units, electromyography, and photoplethysmography/ECG, have gained attention for real-time evaluation of industrial workers' posture, workload, and physiology. Wearable sensors can facilitate early identification of hazardous situations, thereby reducing work-site injuries (Rahman, Md Hadisur, et al., 2023).

"Extended reality," especially "virtual reality," is used to support a safety training system where trainees are immersed in a real-world environment but with no risk. Such an approach amplifies safety awareness and practice without any risk associated with a real environment.

Evidence indicates that exoskeleton technology and robotics can reduce physical effort and ergonomic loading during heavy tasks, with substantial implications for injury prevention and worker welfare.

The article concludes that these emerging technologies collectively represent a paradigm shift toward technology-driven safety and health management. The article, however, identifies a gap in the existing literature, as a qualitative study encompassing a variety of databases is warranted.

## 5 CONCLUSION

Across these three reviews, a common thread emerges: new digital technologies are gradually affecting not only training but also the observation and implementation of a range of complex tasks in healthcare settings and high-risk work environments. In the context of augmented reality, this review indicates that the technology began with a research focus but now supports a wide range of more complex visualizations and interventions. However, it remains challenged in matters of accuracy, available hardware support, and acceptance. Researching 6G technology for m-health takes this a step further in describing future waves of communications technology featuring ultra-high data rate, very low latency, convergence of AI, sensing, and networking, which will soon address new innovative services for real-time telemedicine solutions, remote immersive communications, and surgeries assisted by VR/AR with substantially higher qualities of experience. In this manner, analysis of construction ergonomics underscores this mission goal by highlighting emerging communication technologies. However, wearables, exoskeleton technology, and extended reality have already been deployed on construction sites to reduce labor, enhance hazard awareness, and promote safe working practices. Taken in aggregate, these results indicate that high immersion and connectivity are not separate developments but rather part of a broad, shifting focus toward a safety- and trainee-centered environment, driven by technological support and informed by available data.

On the other hand, across all three reports, it is evident that, in isolation, this potential is insufficient and that various challenges must be addressed before this technology can be deployed at scale, particularly in developing nations. Based on the literature, when augmented reality interfaces, next-generation network technology, and support technology converge, they have immense potential to transform learning, safety, and usability. However, research is needed to understand how this technology can be used outside controlled environments and how it should be used to avoid exacerbating digital inequity.

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**Authors' Contribution**

All authors contributed equally to the development of this article.

**Data availability**

All datasets relevant to this study's findings are fully available within the article.

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