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Adoption of extended reality (XR) technology in Hungarian healthcare

**A bővített valóság (XR) technológia alkalmazása a magyar
egészségügyben**

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1. Introduction

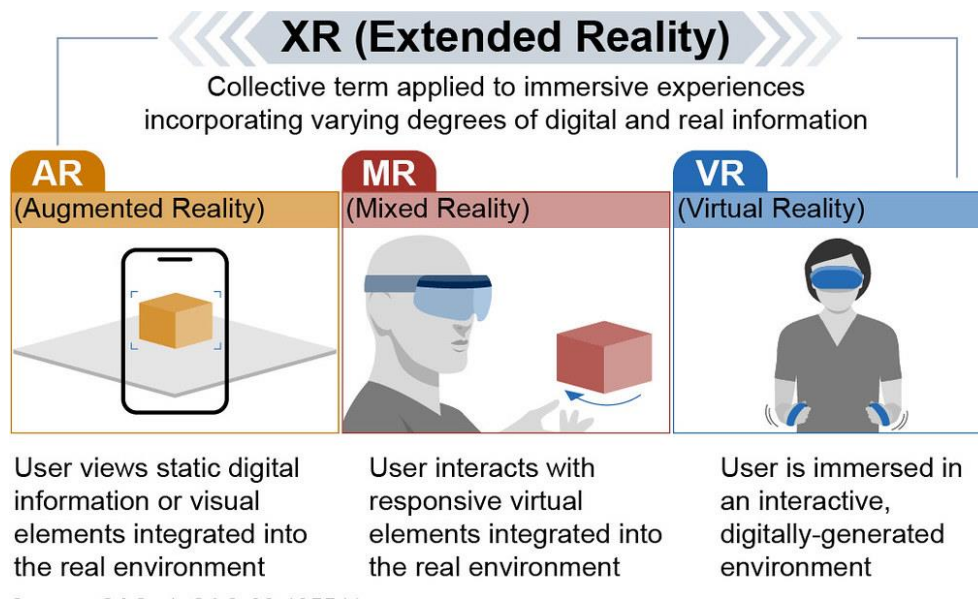
During the past few decades, global investments in healthcare innovations have significantly increased, especially in digital transformation (Zhang et al., 2024). On a global level, healthcare is transforming from traditional hospital-based patient care towards a virtual-based healthcare provision, which utilizes emerging and cutting-edge technologies such as “artificial intelligence, deep learning, data analytics, home-based healthcare, robotics, and three-dimensional printing of tissue and implants” (Wehde, 2019). It is expected that in the future cardinal advancements and changes will completely reshape the healthcare industry (Wehde, 2019).

Despite the significant surge in digital medicine, many devices are still impractical to use in clinical settings. Most devices only provide two-dimensional visuals and can only be used through physical interaction, which is not suitable for the sterile conditions of hospitals, making the understanding of three-dimensional structures quite difficult (Andrews et al., 2019). Improvements in display technology and computing have led to the creation of new devices that are capable of overlaying digital data onto the real environment or incorporating certain components of the real environment into the virtual world. The merging of digital and real environments is commonly called extended realities (XR). Extended reality (XR) tools have various benefits for medical purposes such as three-dimensional visuals and touchless interfaces (Andrews et al., 2019).

Extended reality (XR) technology can contribute to the enhancement of healthcare services to achieve more effective outcomes. Besides providing cheaper treatment and rehabilitation opportunities for patients, extended reality (XR) technology can decrease the cost of medical training and enhance the performance of medical professionals by 230% (Craven et al., 2021).

As researchers have mentioned, extended reality (XR) technology is “an umbrella term for a variety of distinct concepts – most prominently augmented reality (AR) and virtual reality (VR)” (Rauschnabel et al., 2022). Augmented reality (AR) and virtual reality (VR) are different technologies, in augmented reality (AR) the digital data such as objects or instructions are projected on the real environment, while virtual reality (VR) provides a three-dimensional modelled simulation of a real environment (Daling et al., 2023). Figure 1 below gives a brief overview of the technologies that will be the focus of my paper.

Figure 1- Extended Reality (XR) technologies



Source: U.S. Government Accountability Office (2022)

This study explores the use of extended reality (XR) technologies in healthcare and aims to investigate how these technologies can increase efficiency and quality. The analysis techniques are unique in their eclectic approach to studying the application of extended reality (XR) technologies in medical training - both in anatomy learning and in skill-development - through research that combines qualitative and quantitative methodologies to identify processes and key benefits. The main question that I would like to answer in this paper is how extended reality (XR) technologies can improve the efficiency and quality of healthcare.

2. Theoretical Background

2.1. Innovation

In today's healthcare sector, continuous development of products and processes is crucial. A possible advancement area is the integration of extended reality (XR) technologies. Extended reality (XR) usage in the medical field, particularly in healthcare education can revolutionize the way how medical concepts are thought, understood, and bridge the gap between theory and practice (Rowan, 2024).

The scholarship in innovation management has outlined that there are three innovation stages of processes: uncoordinated, segmental, and systematic (Utterback & Abernathy, 1975). The uncoordinated step is the early stage, which represents a period of significant market growth potential, ongoing enhancement, and diversifying competition. In this phase, the changes in

products and processes are rapid. The second stage, known as the segmental step, includes a more mature product that is already participating in price competition, where the competitors are focusing on efficiency. In this phase, processes become more specialized and controlled. Finally, in the systematic stage processes are highly developed and integrated which makes them resistant to rapid restructuring. However, as new technologies become developed, an increasing number of companies leveraging them in product and process innovation become “locked-in” (Utterback & Abernathy, 1975).

In the context of my thesis, medical training is the “product” that goes through the innovation stages, aiming to enhance efficiency and quality through extended reality (XR) technological advancements. The utilization of extended reality (XR) in medical training is still in the primary stage, as this technology has not been formally integrated into the curricula of medical institutions, however, the continuous research and development of the technology indicates the potential value of extended reality (XR) for boosting learning outcomes and skill acquisition (Burian et al., 2023). As the industry advances and these technologies can smoothly be implemented into the already existing training processes, a more coordinated and standardized integration is expected, which also means continuing the transition in the segmental phase (Utterback & Abernathy, 1975).

The research on innovation management has distinguished two types of process innovation: efficiency and quality process innovation. Efficiency innovation focuses on maximizing the efficiency and minimizing the cost of already existing processes by simplifying the process, managing the resources more effectively and reducing operational costs (Peters, 2008). On the contrary, quality innovation focuses on differentiation and meeting customers’ needs by strengthening relationships with suppliers and customers. In most cases, a process can be put into either of these two subcategories (Miles, 2005). However, in the case of the analysed process innovation, the efficiency and quality process innovations are happening simultaneously. The driver of the development in healthcare is quality improvement (especially patient experience) and safety. In addition, it includes performance optimization, risk reduction and value maximization of medical professionals as well which is rather considered as efficiency innovation (DHI Insights, 2023).

2.2 Education

There have been significant changes in the education sectors in the past few years due to new technologies, especially since the pandemic, remote learning has risen exponentially, and new immersive learning environments have been created (GP Bullhound, 2023). Hardware and

software are implemented into training and classroom learning to enhance students' learning experiences by making them more engaging and inclusive especially in; educational institutions (schools, colleges, universities), business training, healthcare, information technology, manufacturing, transportation, and defence (Guze, 2015). In most industries, these improved training processes include different online learning platforms, virtual training modules, simulation (such as extended reality (XR)), virtual labs and webinars (Guze, 2015).

Thanks to extended reality (XR) learners can experience and understand complex materials more practically and interactively. Additionally, this technology provides safer training alternatives in critical fields such as healthcare, fire departments and transportation where the real-life training could cost human lives (Team EMB, 2023).

2.3. Description of Studied Technologies

Extended Reality (XR)

Extended reality is an umbrella term for immersive technologies: virtual reality (VR), augmented reality (AR) and mixed reality (MR). These immersive technologies provide an experience either by combining the real world with a virtual world or creating a completely virtual reality. Thanks to these realities, multiple users can interact at the same time with the same three-dimensional visuals in front of them. Users can navigate the visuals in two different ways: body movements in the real “physical space”, or gesture-controlled movements (such as pointing with fingers) in the “artificial space” (Wexelblat, 2014).

Augmented Reality (AR)

Augmented reality (AR) is the combination of the real and virtual world, it provides virtual images and information projected over the real-world base. This technology improves reality with additional digital details through glasses, screens, or smart devices. While using augmented reality (AR), users can still see and interact with the real environment around them. This technology supports everyday processes in different fields and industries such as medical training, tourism, manufacturing, marketing, service management, and architecture (Rauschnabel et al, 2022).

Virtual Reality (VR)

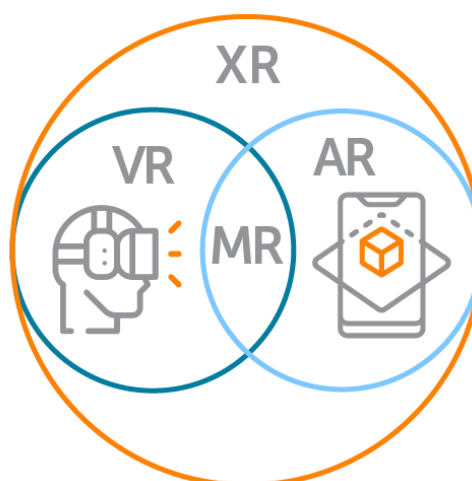
Virtual reality (VR) offers a completely virtual experience for people in a 360-degree view, it is a “computer-generated simulation of a real-life environment” (Zhao et al., 2023). Users need to use a VR headset or ‘head-mounted displays’ (HMDs) and motion-tracking devices to “fool their brain”, believing that the artificial reality is the real world (Rauschnabel et al., 2022). Users

can hear the audio through headphones and engage with the virtual elements using input devices such as joysticks, wands, and data gloves. This allows users to feel as if they are part of the simulated environment and they can look around and move within it (Li et al., 2017). This technology is mostly used in gaming and entertainment industries, however, other areas such as job training, prototyping, marketing, tourism, healthcare, engineering, fashion and military are also applying it with more and more success (Rauschnabel et al., 2022).

Alternative technologies

Mixed reality (or hybrid reality) is often defined differently; however, it generally means the “combination of AR and VR” as it uses both real and virtual details that co-exist with each other in real time. This technology enables the connection of digital elements to specific points in the real world hence users can engage with the digital object in different ways (they are not just digital overlays). During the past few years, the meaning of MR has gotten closer to” realistic AR” due to the launch of new devices, hence there might be a redefinition of the word “MR” in the upcoming years (Rauschnabel et al, 2022). In the following, Figure 2 shows the grouping of the previously mentioned technologies.

Figure 2 – extended reality (XR) as an “umbrella term”



Source: Ergomania (2022)

2.4. Benefits of Extended Reality (XR) Technologies

There are different benefits of extended realities (XR) in different industries. In educational institutions, thanks to innovative technologies, especially virtual reality (VR), students can engage in diverse learning approaches beyond traditional in-person classes. Virtual reality (VR) makes learning materials accessible to everyone, including disabled or home-schooled students (Fussell & Truong, 2021).

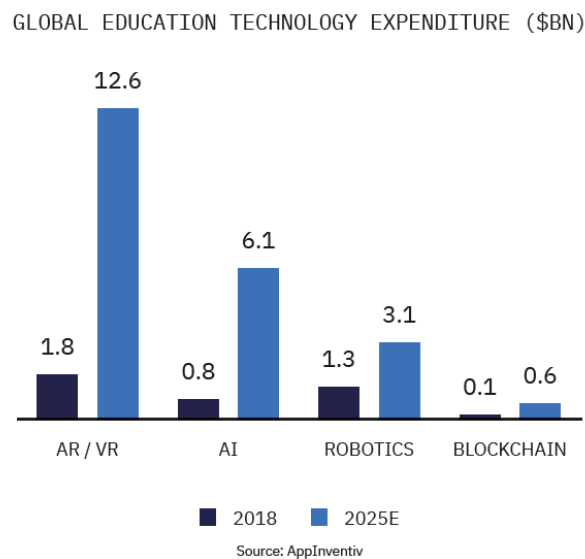
In manufacturing augmented reality (AR) can save a lot of time for the workers as it can recognize different objects and show crucial information over the real “view”, and in this way, the employees can read the most important information without going through numerous manuals. Furthermore, manufacturing training can be organized in a managed and protected virtual place, hence it can decrease the number of faults and improve productivity and quality. At the same time, extended realities (XR) play a crucial role in transportation, particularly in pilot training, offering cost-effective solutions and additional benefits by allowing learners to practice various manoeuvres safely without putting human lives at risk" (Fussell & Truong, 2021).

In healthcare extended realities (XR) can be used for different purposes including professional training and patient care in various fields such as radiology, surgeries and special procedures to improve results and reduce failure rate (Team EMB, 2023). The use of extended realities (XR) in medical universities includes e-learning opportunities which enable students to learn independently, self-direct their learning journey, study anytime and anywhere, and receive feedback immediately (Saffari et al., 2014). Moreover, thanks to the combination of extended realities (XR) and Artificial Intelligence (AI), students can gain knowledge and skills from simulations and interactive experiences that stimulate all the senses (listening, reading, and seeing), which is a remarkable advancement as the traditional education methods only involved reading and listening exercises. As the report of GP Bullhound shows, extended realities (XR) contribute to information retention and better understanding of complex materials, while also emphasizing student engagement which may not be possible through traditional teaching methods (GP Bullhound, 2023).

As GP. Bullhound’s predictions mention, that even though the cost of investigating extended realities is notable, there is a continuously increasing interest in it. For instance, in the United

States, educational technology ¹firms secured \$5.2 billion in investment funding in 2022, largely due to the growing demand for personalized learning (GP Bullhound, 2023). As the following Figure 3 shows, the investments in extended realities (XR) for training purposes are expected to be 7x higher than in the year 2018 (GP Bullhound, 2023).

Figure 3 - Expected Investment for extended realities (XR) in training



Source: GP Bullhound (2023)

2.5. The Application Studied Technologies in Healthcare

In the medical field, professionals need life-long learning even after the challenging medical education at universities. There is an ongoing need for more efficient patient care for which the only feasible way is digitalization. Furthermore, there is an increased emphasis on patient safety which impacts all the steps of medical education (Guze, 2015). By integrating new technologies including computer-assisted learning (such as checking the online lecture in advance of the seminars), medical apps (e.g. with medical questions), digital games (practising surgical steps), simulations and wearable technical devices, medical education and skill training can significantly be advanced (Guze, 2015).

2.5.1. Simulations

Simulations are one of the most prominent technological tools for education in healthcare as many devices have been created for simulating real clinical tasks, patients, and circumstances.

¹ “analysing, designing, developing, implementing, and evaluating the instructional environment, learning materials, learners, and the learning process in order to improve teaching and learning” (Loyola University Maryland, 2021)

By practising simulations, medical students and professionals can continuously receive feedback, choose the difficulty level of the task, experience a variety of clinical situations, personalize their learning and exercise in a controlled environment. Based on Issenberg's statement the quality of already existing simulations needs to be further developed, however, they are already contributing remarkably to the skillset of medical professionals as simulation provides an effective way of practising and can successfully supplement hospital training (Issenberg et al., 2005).

There are different types of simulations in medical training such as reproductions of separate body parts, whole body replications, Harvey simulator (for cardiac examination), Haptic systems (kinaesthetic replication), mannequins with controllable parameters and extended realities (VR, AR, MR). Augmented reality (AR) tools can project 3D anatomy pictures over 2D illustrations that can help medical students understand the structure of the different human parts. Additionally, virtual reality (VR), which is considered among the most advanced simulations, provides a completely non-real environment for practice (Guze, 2015). In Appendix 1, 2 figures visualize the use of extended realities (XR) in medical settings.

2.5.2. Current Uses of the Technologies in Healthcare

The application of extended realities (XR) is getting more common in the medical field, and they are already used in “physical rehabilitation, pain management, surgery practices, anatomy education and psychiatric treatment”. In surgical practices, extended realities (XR) have an emphasis on the connection with the medical tools used during the surgery (Li et al., 2017).

For a long time, medical students could only obtain surgical skills by observing and practising in the operating room supervised by the resident surgeon. However, due to the increasing number of junior doctors, there was not enough time for them to practise even though the senior surgeons stayed overtime. This led to the fact that trainee doctors didn't receive sufficient practice hence they couldn't gain enough skills, especially with the developing surgical techniques that would have required training (Li et al., 2017).

By implementing virtual reality (VR) training before the real operating room practices, institutions can save time and increase efficiency as well as precision. During virtual reality (VR) surgical training junior doctors can work with anatomical body parts and receive feedback on the performance. Due to this virtual reality (VR) technology no additional people (senior surgeon, patient) are needed for surgical practices. Furthermore, trainees can repeat the training as many times as they want and develop their skills based on their results, including information

on “time necessary to complete task, path length, number of collisions, injuries, number of anatomic landmarks identified, number of loose bodies found” (Li et al., 2017).

2.6. Technology Training for Medical Professionals in the United States

2.6.1. Training for Anatomy Learning

In the University of Central Florida College of Nursing augmented reality (AR) and virtual reality (VR) technologies are integrated into the anatomy learning materials. Due to the capabilities of these immersive technologies medical students can “see inside and walk in the human body”, in this way the learners can see what happens within the body for instance during a heart attack. For instance, thanks to augmented reality (AR), students have the opportunity to witness both typical and problematic births, this firsthand experience enables learners” to identify abnormalities sooner and take early intervention measures, ultimately leading to improved patient outcomes” (Horowitz, 2022).

2.6.2. Training for Skill-development

The Johns Hopkins School of Nursing provides virtual reality (VR) training for different professionals at different levels, they focus for instance on CPR (cardiopulmonary resuscitation) and management after the surgeries both for children and adults. Their medical virtual reality (VR) training includes hand haptics; however, it emphasizes more on the cognitive decision-making of professionals. The artificial intelligence (AI) integrated into the training assures that decisions are made based on time-critical decisions (Horowitz, 2022).

At Massachusetts General Hospital virtual reality (VR) headsets are used for training medical students and residents in motor skills that are essential for surgeries. Thanks to technology, professors/doctors can connect their computers to the VR glasses and see exactly what the learners see in their virtual reality (VR) headsets and instruct them. Additionally, this virtual reality (VR) equipment enables students to practise the procedures numerous times. For example, thanks to virtual reality (VR) orthopaedic students can learn precisely how to make certain procedures and shoot X-rays the correct way without practising on real patients (Horowitz, 2022).

The Johnson & Johnson Institute established a global virtual reality (VR) training program to teach orthopaedic surgeons, nurses, and medical students how to perform numerous procedures by applying certain advanced digital equipment. Johnson & Johnson makes collaborations with hospitals that have residency programmes. The J&J virtual program includes numerous modules which take place in virtual operating rooms that are accessible by virtual reality (VR) headsets. The virtual 3D operating room has examination lights, instrument tables, a patient and

everything else which would be in a real-life operation room. As soon as the learners acclimatize to the virtual environment, the program starts to guide the learners through the procedure by explaining every step and instrument needed. The learners can re-do the procedure as many times as they want, and it is possible to turn off the directions. Additionally, the software immediately sends feedback about each step of the learner, it detects wrong steps, sequences or tool use immediately. Thanks to this programme and the infinite practising opportunities, medical students and professionals can “reduce real-life mistakes and surgery complications”. Learners can practice in a safe and controlled environment without experimenting on a human, additional they can study and practice at their own pace until they become precise enough in certain procedures (Arsene, 2018). Additionally, as “the first pre-clinical study on the technology showed, the use of the technology resulted in 85% accuracy compared to 64% accuracy in the case of conventional techniques” (EOS Intelligence, 2018).

2.7. Advantages of the Adoption of the Studied Technologies in Healthcare

Thanks to extended realities (XR) hospitals can create calming and distracting experiences for patients undergoing medical procedures or dealing with chronic pain. This can significantly reduce pain, anxiety and stress experienced by the patients. Moreover, extended realities (XR) make remote consultations possible (without the need for physical presence) which can be valuable for individuals in remote areas or those with mobility issues (Jump Growth, 2022).

Extended realities (XR) provide realistic and immersive simulations for medical training, allowing students and professionals to practice different procedures in a controlled environment. This hands-on experience enhances their skills and confidence and reduces the possibility of errors during in-hospital patient care. Furthermore, extended realities (XR) help medical imaging interpretation, by making better visualization and understanding of complex anatomical structures, which contributes to more accurate diagnoses and efficient treatment planning (Jump Growth, 2022).

In the long term, virtual reality extended reality (XR) proves to be more cost-effective compared to traditional medical training due to its scalability. For instance, virtual reality (VR) requires a significant investment in the beginning but from that on it offers unlimited “repetition of training scenarios, remote access, customizable features”, and continuous development for all learners, at the same time with regular software improvements, the materials can always be up-to date (UbiSim, 2023). As virtual reality (VR) devices for healthcare applications become more affordable, the initial investment cost will be reduced, which will further encourage the adoption of virtual reality (VR) technology within the sector (EOS Intelligence, 2018). Also, based on

UbiSim's research after 3 years virtual reality (VR) trainings have financial advantages over traditional methods, as the yearly hospital, medical training costs per participant are \$327.78 with in-hospital exercises and only \$115.43 with virtual reality (VR) training (UbiSim, 2023).

3. Problem Definition

Hungary, as most Central and Eastern European countries, mainly relies on its public healthcare which is funded from taxes and social security contributions of the citizens and is regulated by the government. At the same time, public healthcare is rapidly evolving in the country to provide faster access and more specialized treatment. (Łyszczarz, 2016).

PESTEL Analysis of the Hungarian Healthcare Services

Political:

The local government policies and regulations heavily impact the Hungarian healthcare system. Additionally, the decisions made by the governments on healthcare funding and budget allocation influence the accessibility of resources to improve the infrastructure and technology of the health sector (Tambor et al., 2021). The regulatory environments (including European Union regulations) can approve certain medical devices and digital health solutions that can significantly contribute to the speed of technology adoption. Besides, collaborations with international organisations can increase the healthcare standards of Hungary.

Economic:

The economic stability of the country influences the healthcare's capacity to invest in or adopt new technologies as economic downturns may constrain healthcare budgets and slow down technology adoption. For instance, the notable changes in exchange rates of the local currency can lead to the unaffordability of certain medical devices and pharmaceuticals.

Social:

As Hungary has an ageing population, the change in demographics also affects the need for healthcare and the demand for innovative healthcare solutions especially for elderly care and chronic disease management (Botev, 2012). Moreover, the perception of patients towards new technologies is crucial as without acceptance, trust and data privacy measures, integrating new technologies into healthcare can face notable difficulties.

Technological:

The Hungarian healthcare system has already adopted digital health solutions to enhance the efficiency of data management and improve patient outcomes. Additional investments in R&D (Research and Development) can further contribute to healthcare development through new medical tools and treatments.

Environmental:

As a country, being prepared for emergencies such as pandemics is essential to healthcare system resilience.

Legal:

To have the trust of patients, the local government needs to have strict data privacy regulations and cybersecurity protocols, also these laws have to be compliant with the European Union regulations and general international standards. Additionally, emphasizing regulations concerning intellectual property rights can lead to broader availability of patented medical technologies.

Based on this environmental analysis of Hungarian healthcare, this study has the primary objective of answering the question of how extended reality (XR) technologies can improve the efficiency and quality of healthcare. In addition, this research aims to provide insights as to how this technology improves skill development.

4. Methodology

This research is based on a collection of primary data using a qualitative and quantitative research methodology. The two research methodologies have been designed to complement each other, each contributing specific insights to address the research question. The primary research methodology of this study involved conducting interviews and collecting qualitative data from industry practitioners, for this research to explore new information and collect new relevant data to answer the research questions. The secondary methodology, although consecutively conducted, involved collecting quantitative responses by administering surveys from respondents, to validate propositions and information collected by primary research methodology. As Ilona Ida Balog stated “Now it is hard to imagine any well-based research purely from a quantitative or qualitative point of view. Qualitative methods without quantification and tests are simply not verifiable” (Balog, 2020). Also, “mixed methods can address complex research questions with more accuracy due to their three main characteristics: generalizability, contextualization, and credibility” (Sardana et al., 2023).

As there is only limited research available on the topic of implementing extended reality (XR) technologies into medical training, and the majority of them seems to originate from the United States and focus on the health institutions of the United States, my goal was to investigate the topic in the Central and Eastern European region. As virtual reality (VR) and augmented reality (AR) haven't been deeply implemented into the training of medical professionals yet, the possible efficiency and quality improvement impact of these technologies was important to analyse. My research started by first making interviews, hence gathering qualitative data which was followed by quantitative data collection for validating the findings of the quantitative approach. This mixed method enabled a comprehensive exploration of my research topic while ensuring the validation of findings across different data collection methods.

4.1. Qualitative Research Methodology

In my qualitative analyses, I applied the methodology of semi-structured interviews, which gave me the possibility to ask several closed and open-ended questions from the respondents, sometimes continuing with follow-up questions. This research methodology enabled respondents to freely articulate their thoughts and perspectives, provide additional insights and contribute to the broader context of the analysis. The sample of respondents was randomly selected from the population of professionals relevant to the analysis. For the sample to qualify for the qualitative research a respondent needed to be an entrepreneur who is working on a project, or start-up related to the application of extended realities (XR) in medical training. The sample consisted of 6, coming from various backgrounds such as medical surgeons, dentists, anatomy professors, engineers and economists, who provided 6 full observations.

The interview protocol refinement ("IPR") framework was then applied to create and improve the interviews, which involved several phases: 1) verifying that interview questions were in line with the research questions, 2) building a dialogue around the questions, 3) gathering feedback on the interview protocol, 4) "piloting the interview protocol" (Shoozan & Mohamad, 2024). The aim of aligning themes with interview questions was to enhance the effectiveness of the questions and ensure valuable data collection within the limited timeframes of my research. The open-ended questions aimed to gather information on each topic during discussions, encouraging respondents to share and elaborate on their individual experiences and perspectives. After pre-testing the interview with one participant and analysing the comments from that session, the final interview was created and then launched to the sample of respondents. In appendix 2 my "Interview Protocol Matrix for Qualitative Research" is enclosed (Appendix 2: Interview Protocol Matrix for Qualitative Research).

The objective of the interviews was to collect insights and ideas from respondents in two areas of inquiry:

- There are benefits of leveraging new technology in healthcare.
- New technology can be integrated into professional training processes

The semi-structured interviews were conducted to explore the motivation of professionals, their views on the advantages of the technology, potential factors enhancing quality and efficiency, the technology's impact on skill development, and methods for measuring its effectiveness. The interviews were conducted separately via video conference through Microsoft Teams application where respondents were asked five open-ended interview questions. The respondents received the interview questions before the online meeting, there no additional question was asked. Each interview lasted about 25-40 minutes and most of them were audio-recorded (with participant consent) and in English. The online interviews were conducted between the 20th and 25th of March 2024.

Afterwards, the recordings and notes were transcribed and manually coded based on key concepts and then reorganized into thematic categories. Appendix 2 contains an interview matrix where the interview questions are listed in rows, while the themes to be explored are listed in columns (Appendix 2: Interview Protocol Matrix for Qualitative Research). Additionally, an Excel sheet is attached to the appendix which shows the analysis and coding of the interviews (Appendix 3: Qualitative Observations).

4.2. Quantitative Research Methodology

For the follow-on quantitative research, an online survey was conducted with a convenience sampling, targeted population of medical students in hu who have already learned anatomy and participated in skill training. Convenience sampling was utilized to distribute the survey among students enrolled in medical programs across various institutions. The questionnaire was conducted in English and between the dates between the 2nd and 9th of April 2024.

A total of 52 full observations were collected during the mentioned period. The survey was created based on the themes and insights from the interview findings and aimed to validate the qualitative data through the quantitative approach. Also, it provided quantitative information on experiences, preferences, and perceptions regarding medical education. The survey was created online using Google forms and contained only closed-ended questions with agree-scale responses. Later, the gathered quantitative data was analysed through statistical software, which summarized the data collected from participants.

The survey contained 3 introductory questions to affirm that the respondent is from a Hungarian medical university and has already participated in anatomy and skill training. The survey asked respondents about their perceptions of 10 unique statements relevant to the research questions (Appendix 4: Survey Questions). The results were collected by a Likert scale and were administered on a 5-point scale of strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, and strongly disagree. The survey that I created was drafted around variables that were based on the relevant thematic areas. The first thematic area was extended reality (XR) in learning which included the following variables: Use of technologies, Difficulties with anatomy, and Practicing. The second thematic area, namely extended reality (XR) in skill development included the “Learner’s performance, Additional information, Precision” variables. The survey included only focused questions to eliminate noise in the data. Since this profession is limited in the size of its population, I judged there was no need to conduct a robustness test to confirm the representativeness of the samples for the population studied.

The first two questions of the survey were asked about the respondent’s background. (“Have you studied at a Hungarian medical university or are you currently enrolled at one?” and “Have you so far attended anatomy classes and its training sessions?”) As 100% of the participants answered these questions with a “yes”, they all met the criteria of my quantitative research. Considering there are currently four medical universities in Hungary, to gather information on which universities students have filled out the questionnaire from, the third question was: “Which university have you attended/are you attending?”. Based on the answers, the participants represented all the Hungarian medical institutions. The survey was filled out by 29 students from Semmelweis University, 12 students from the University of Szeged, 7 students from the University of Pécs, 3 students from the University of Debrecen and 1 student from another institution.

The following 10 statements of the survey were answers of the entrepreneur interviewees, and the medical students could rate them on a scale from agree to disagree. Overall, to each of the questions, at least 69,9% and a maximum of 94,3% of respondents answered with an agree or somewhat agree. Which means that they sympathized with the acknowledgements of the interviewees.

As might be expected this mixed method can have some limitations since the research was conducted within the context of Hungary which may have unique cultural, and regulatory factors that influence the findings. Moreover, as the research was collected at one point in time,

it has some further limitations as technology changes rapidly hence the relevance and applicability of the findings can change over time. Besides, respondents and sample biases might limit the research as well as it is always possible that respondents do not completely understand the question or that they find it difficult to answer certain questions.

5. Problem Analysis

5.1. Results of the Qualitative Research and their Interpretation

The interviews were conducted to gather information on the use of extended realities (XR) in medical training in Hungary. 6 Hungarian entrepreneurs were asked to share their views on this specific market and the possible advantages of these technologies in health-related fields.

5.1.1. Background and Motivation

All participants were first asked about their interest and motivation to work on a project focusing on extended realities in healthcare.

Four respondents stated that they come from a medical background, two of them are working as surgeons, one as a dentist, and one as an anatomy professor. From a surgeon's perspective, they understood early in their career that new technologies would significantly improve healthcare. For surgeons, the first ten years are considered the start of their career because various slowly acquired skills are needed for the profession, however, they believe that thanks to these technologies, skills can be advanced and learned faster. From the anatomy professor's viewpoint, extended realities (XR) are important to better visualize structures in three-dimensional, and they could be an excellent B option for cadavers. Also, these immersive technologies can significantly impact the cost structure of healthcare. The other two participants came from engineering and economics and met with these technologies through university programmes and immediately felt the importance and the possibilities of these technologies in health-related fields.

Overall, four respondents said that their curiosity and openness led them to explore this field on a deeper level as previously they had only worked in traditional, non-technology-based divisions. Additionally, two participants answered that they have already used the technology because they like computer games and three-dimensional modelling. Also, they knew that it has huge potential to improve education, however, it has not yet been deeply implemented in the European region. The third respondent has already worked at a research department in Norway and in Canada which was working on virtual reality (VR) technology for guided treatments and

operating theatres as surgical planning options, and he wanted to use his knowledge to implement the technology in the healthcare of Central and Eastern Europe.

In the second interview section, all participants were asked to share their perspectives on the benefits of extended reality technology in medical training and healthcare. Overall, the respondents stated various areas, namely: telecommunication, anatomy learning, skill development, surgeries, complications, and cost where these technologies make the most beneficial impacts.

5.1.2. Benefits in Anatomy Learning

Five out of six respondents emphasized the importance of virtual reality (VR) in anatomy learning during the first years of medical university. Four respondents, who come from medical backgrounds, mentioned that in many subjects such as anatomy and molecular biology, students have to memorize huge amounts of learning material and visualize three-dimensional structures, that are only available in two-dimensional graphics in books.

The second respondent pointed out that in Eastern Europe 45-50% of medical students drop out of medical school because of the anatomy exams”. Three respondents agreed that implementing virtual reality (VR) into medical training and hence providing opportunities for students to enhance their “three-dimensional way of thinking”, could significantly make the learning process easier and faster. Thanks to this technology students could not just watch the anatomical structures in three dimensions as in YouTube videos but could walk around the body parts, enlarge, unhide the details, rotate them, and could understand the connection points more effectively. In this way, students could understand the material on a much deeper level and learn the topics much faster.

Two respondents emphasised the cadaver base of anatomy teaching in Eastern Europe. They detailed how in many countries; students learn anatomy structures on the same cadavers for years and then at the end of their studies the university pays for the funeral (which is quite expensive) that the whole class attends. The fifth respondent pointed out that because of the financials of the funeral, currently there is no shortage of cadavers in Hungary, however, in many countries, people cadavers are not available because of cultural and religious reasons hence students only minimally meet with human bodies before becoming doctors. Even in Hungary, a whole class has only one cadaver which means that there is not enough place and time for everyone to practice. Additionally, cadavers can get damaged easily, hence in many cases some body parts get lost, and the students must imagine that certain body parts are there.

By using virtual reality (VR) in anatomy seminars students could practice simultaneously with the goggles and cadavers. Moreover, as the first respondent mentioned, it would be possible to follow what the professor is doing by using their smartphones as displays. Students could see on their phones what the professor sees in his/her goggles even when there are numerous students in the seminar and if they cannot stand close to the cadavers.

5.1.3. Benefits in Skill-development

All the respondents pointed out the beneficial effects of applying extended realities (XR) in skill training both for medical students and professionals. Thanks to these technologies various medical situations and scenarios can be simulated and practiced before doing it on real patients. Additionally, two interviewees said that currently there are only two simulation centres in Hungary in Pécs and Budapest, but neither of them has extended reality (XR) technologies, hence these technologies would provide completely new opportunities in the country.

Application of Augmented Reality (AR) technology

All of the respondents agreed that generally medical students have a slow and long learning curve as even “easy tasks” need to be practiced for years. Before working in a medical role that requires refined manual skills such as suturing during procedures, the learners have to practice hundreds or even thousands of times, first on pig skin, then on artificial bodies and later on real patients under the supervision of professors. By applying augmented reality (AR) goggles, learners could see the correct angle and pressure needed to make the sutures projected over the skin which would make the skill acquisition easier. Also, the third respondent pointed out that during the practices through augmented reality (AR) goggles, the attendance of professors is not required as the software using Artificial Intelligence (AI) can objectively give feedback on the movements, and steps made by the learner. Furthermore, the second respondent stated that by receiving objective feedback, students could get suggestions about what should they improve, and they could further practice it at home as many times as they want. In the application, the learners can see their progress with numbers and can compare it to previous practices (such as how many minutes could they finish the procedure, in how many stitches they closed a wound).

Application of Virtual Reality (VR) technology

Regarding the benefits of using virtual reality (VR) in skill training, Besides, four respondents claimed that the use of virtual reality (VR) technology makes skill acquisition more efficient. As two respondents mentioned, the students can practice the same tasks such as blood taking

or cutting on different patients with tissue types and learn how much pressure they should put on different tools. Thanks to virtual reality (VR), students not only feel where they insert the needle but can see what kind of vessel is under their skin. In this way, it can significantly decrease the length of the procedures and the possibility of complications.

Furthermore, half of the respondents said practising first on lifelike scenarios and not on real patients can decrease the stress and anxiety felt by learners and make them less stressed when first being in a similar real situation. In addition, it is also beneficial for the patient as students won't attempt certain tasks on them for the first time. Furthermore, two respondents mentioned that by creating three-dimensional printed phantom models and integrating Artificial Intelligence (AI) into the virtual patient – hence creating personalized virtual patients - the learners could even practice communication, and question-asking during examination. Additionally, two participants emphasised the need for life-long learning for medical professionals. As renewing medical licences every 5 years is required in various countries, continuous learning and participation in training is necessary for medical professionals. Thanks to virtual reality (VR) technologies professionals who already have a general knowledge and skillset wouldn't necessarily have to go to a hospital or to a simulation centre to practice, but they could exercise from home on simulations. The following Table 1 provides an overview of the benefits of extended reality (XR) technologies in anatomy learning and skill-development.

Table 1 – Benefits in Anatomy Learning and Skill-Development

	Stress and anxiety	Learning curve	3D visualization	Visual guides	Obective feedback	Lifelike scenarios
Respondent 1	X	X			X	X
Respondent 2		X	X	X	X	X
Respondent 3		X	X	X	X	X
Respondent 4		X	X			X
Respondent 5	X	X	X			X
Respondent 6	X	X	X	X	X	X

Source: Own Research

5.1.4. Benefits in Healthcare

Regarding the benefits in healthcare, the respondents highlighted the following areas: telecommunication, telemedicine, complications, costs, surgical procedures, and patients. These areas are all connected and can be discussed as part of bigger topics.

Telemedicine

Half of the respondents said that telecommunication, telemedicine is one of the most remarkable benefits of extended realities in healthcare. One respondent mentioned that thanks to these technologies when hiring a new surgeon, they could already show the interviewee the exact dimensions and equipment of the operating room before going to the hospital. Additionally, thanks to virtual reality (VR) doctors all around the world can learn together in a virtual environment such as Metaverse Zoom and can participate in the same training at the same time. Besides, as the sixth respondent observed when a doctor must perform a rare procedure, a specialist doctor can join him/ her in a virtual environment and show the surgery step by step and help him/her verbally during the whole procedure while seeing the ongoing surgery. Also, oncology teams where around 4-6 doctors must attend a meeting before starting a treatment, can discuss the treatment plan.

Surgeries

Four out of six respondents commented on the benefits of augmented reality (AR) in different surgical planning and during surgeries. They emphasized that thanks to medical imaging technology professionals can see the special anatomy of each patient which cannot be seen from outside. However, doctors have to constantly switch between the screen and the patient to make the correct diagnosis and surgical plan. By applying the goggles, professionals could see the projected MRI, and CT scans over the body parts and organs hence predicting the location of vessels precisely and preventing the damage to organs and vessels. In this way, surgeries can be more precise and safer which is extremely important for tumour surgeries. Aside from that, as one of the respondents remarked “in certain surgeries the uttermost experience and mental stability are needed through operations” and with the navigation and guidance of the technology there is a decrease in possible risks. When only using the digital images of CT and MRI, it is possible to lose some important information which leads to higher risks and complications through the surgeries.

In addition, the second respondent said that if all the information, preoperative surgical plans could be projected over the patient during tumour surgeries, surgeons would need to cut by following the visualized dotted lines which would make the task a lot easier and safer in this way as much health tissue could be prevented as possible. Thanks to this technology implementation hundreds or thousands of people could be treated without the need for second and third operations because of remaining tumours that could spread further. This leads to not

only the help of patients but society overall as it can preserve huge amounts of money for the government. Furthermore, the 5th respondent declared that if surgeons wore goggles during surgeries, the software would immediately alert the professional if there was an additional object left in the patient such as a towel. This would reduce the number of medical malpractices, which generally cost a lot of extra money for the hospital because of the unplanned follow-on surgeries, treatments, and legal expenses. In this way, extended realities could minimize the number of human errors and decrease the cost of hospitals. The following Table 2 shows an overview of the benefits of extended reality technologies (XR) in healthcare.

Table 2- Benefits in Healthcare

	Telemedicine	Surgical planning, surgeries	Patients	Medical malpractices, complications	Costs
Respondent 1	X				
Respondent 2		X	X	X	X
Respondent 3	X				X
Respondent 4		X		X	
Respondent 5		X		X	X
Respondent 6	X	X	X	X	

Source: Own Research

In the last segment of the interview, the respondents were questioned about the effectiveness of these extended reality (XR) technologies in medical training and methods for evaluating their efficacy. The topic regarding the measurement of effectiveness was accessed by the respondents from two different perspectives, from medical and technology based as well as from the subjective and objective approach.

5.1.5. Efficiency in Anatomy Learning

One of the interviewees said that he struggled a lot with learning for and passing the anatomical exams as they “had to sit down with thick books and memorize everything without comprehension or time to think during the exam”. He said that many of the medical students face difficulties with the anatomy subject and receive low grades. Also, the second respondent pointed out the emotional and psychological aspects faced by medical students during exam periods and when experiencing failures which could lead to doubts about their future skills as a professional. He highlighted that based on the comparison of traditional and emerging technological education in other fields, research shows significant differences in grades in favour of the digital one. Students can learn easier, faster and get better marks. The third interviewee responded that many people could learn better if they visually see the structures especially in three-dimension, hence for them, the hours needed to learn certain materials can be reduced remarkably by implementing extended realities. Additionally, the 4th respondent

emphasised that by providing visuals in three-dimension for students, they could easily understand the details and could receive better grades.

Furthermore, the last respondent mentioned how important it is to maintain the attention of the students, and that nowadays the attention span is getting shorter hence it is harder to keep the students active during classes. Thanks to extended realities an addictive learning programme, similar to the Duolingo app could be created where students can walk within the virtual environment and learn with visuals, texts and sounds which would help them learn the concepts, structure faster and repeat the parts where their results were not sufficient. Also, walking within the virtual environment could contribute to the decrease in time needed to learn materials as doing repetitive movements while studying helps memorization. Traditional anatomy learning groups could be compared to ones that use extended realities based on their exam result and performance during the semester in this way the effectiveness of the technologies could be measured.

5.1.6. Efficiency in Skill-development

All the respondents agreed that it is not easy to measure the effectiveness of extended realities objectively in skill training. Based on two respondents' answers, from a technological perspective, the efficiency of extended realities (XR) can be measured successfully in skill training if it is highly accurate and tracks the movements within a short distance quickly, for which a highly sensitive software is needed. The technology has already improved a lot in the past 5 years and is expected to exponentially develop in the following years.

One of the respondents answered that by integrating a ticking clock into the software, the result and improvement of learners could be measured objectively based on time. Generally, in the beginning, students may not be able to complete the task or need a lot more time than later. Additionally, efficiency can be also measured based on the pressure put on the medical tools and whether they would cut through real skin. The last respondent also mentioned that professors could subjectively compare students' first stitches and check if the ones who already practised it virtually could perform more efficiently than those who had not.

Three of the respondents claimed that possibly the best option to measure the effectiveness of these immersive technologies in skill training from a medical perspective is to collect data about surgeons from universities and speciality training. Based on this data an average learning curve can be created on how long it takes to become a surgeon. The learning curve of students who learned with the traditional methods can be compared to the students who learned with the new,

technological methods. All respondents agreed that this technology is not yet well spread, especially in Eastern Europe, hence there is no current data on its effectiveness. However, they all believe that this technology will become present in medical universities, hospitals, and other educational institutions within 5 or 10 years.

Moreover, in older institutions, doctors who applied these technologies and those who learned traditionally can be compared to each other based on error rates, costs because of errors and the rate of operations that needed to be re-performed which all contribute to efficiency. Besides, four respondents pointed out the importance of tracking the well-being and feelings of learners. When first using immersive technologies, students tend to be more stressed however, as time goes by, learners feel less anxious and get used to the goggles. Also, it would be interesting to compare how professionals with different learning backgrounds feel after their first on-patient surgeries. The following Table 3 gives an overview of how the efficiency of extended reality (XR) technology can be measured in the medical field.

Table 3 – Measuring efficiency in anatomy learning and skill-development

	Exam, exercise results	Accuracy	Time	Comparing to traditional methods	Well-being
Respondent 1			X		X
Respondent 2				X	X
Respondent 3	X	X			
Respondent 4		X			
Respondent 5				X	
Respondent 6	X		X	X	X

Source: Own Research

5.2. Results of the Quantitative Research and their Interpretation

5.2.1. Extended Reality (XR) in Anatomy Learning

In the first segment of the survey, I collected data on the students' openness and willingness to use extended reality tools in their education and training. As currently extended reality (XR) is not yet implemented at all in general medical education in Hungary, it was important to know how the students approach the topic. As all the following statements were focused on possible specialized impacts of these immersive technologies if most of the students had responded with a "disagree" to this section, the whole meaning of the survey would have been questionable. Fortunately, the majority of the respondents chose "agree", 20 of the students chose "somewhat agree" and no one chose the answer "strongly disagree". In this way, there is no doubt that Hungarian medical students have an interest in exploring and leveraging extended reality (XR) tools for educational purposes. Besides, they likely see the value and potential benefits that

these innovative technologies can offer for learners. Table 4 and Figure 4 below visualize the responses from the quantitative research.

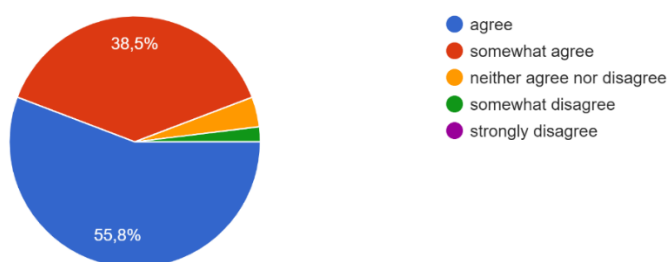
Table 4 - Collected Quantitative Data from Surveys

	Percentage of respondents	Number of respondents
Agree	55,8 %	29
Somewhat agree	38,5 %	20
Neither agree nor disagree	3,8 %	2
Somewhat disagree	1,9 %	1
Strongly disagree	0 %	0

Source: Own Research

Figure 4 - Collected Quantitative Data from Surveys

I am interested in using Virtual Reality and Augmented Reality tools in education and training.
52 válasz



Source: Own Research

The second segment of the survey included statements regarding the current difficulties of anatomy learning and possible learning process improvements. Currently, in Hungary, students can understand and practice the structure of the human body on cadavers during classes. Besides that, only 2dimensional non-realistic beautiful drawings are available for students in atlases to study at home. As 78,9% of the participants, 41 students answered that they find anatomy learning materials to be challenging, it is evident that some kind of change or development is needed in that area of education.

It is quite challenging for students to understand the inner structure of the body parts as on the cadavers many times they cannot see the little details and in the anatomy books they only see the structures in 2D, hence it is difficult to imagine and understand them 3 dimensionally. Based on the answers of the students it is obvious that extended realities (XR) would help them understand the structures better and make their learning process faster. This conclusion comes

from 48 (92,3%) students selecting either "agree" or "somewhat agree" in response to the related statements. Table 5 and Figure 5 below visualizes the responses from the quantitative research.

Table 5 - Collected Quantitative Data from Surveys

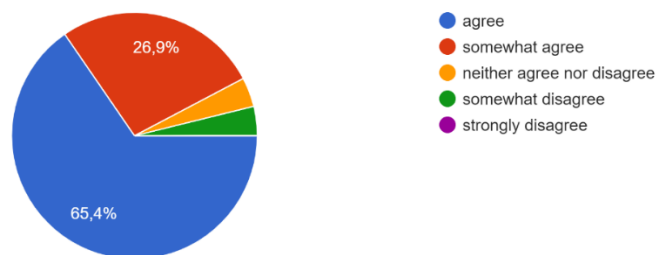
	Percentage of respondents	Number of respondents
Agree	65,4 %	34
Somewhat agree	26,9 %	14
Neither agree nor disagree	3,8 %	2
Somewhat disagree	3,8 %	2
Strongly disagree	0 %	0

Source: Own Research

Figure 5 - Collected Quantitative Data from Surveys

I believe that using Augmented and Virtual Reality to visualize anatomical structures in 3D would enhance my understanding of anatomy and make my learning process faster.

52 válasz



Source: Own Research

Additionally, 47 survey takers stated that they would practice the anatomical structures from home even after the practical classes if extended reality (XR) tools were available. This indicates that for students, 3D visualization is crucial and contributes significantly to understanding complex concepts. Furthermore, one of the students added that it would be useful to have extended reality (XR) to help them study at home, however, as they have to present everything on dead bodies during anatomy exams, having not only “3D modelled structures” but images of dead bodies could further contribute to their better understanding. This information supports the idea that extended reality (XR) could provide additional help for students, however, could not entirely replace the use of cadavers - at least not in the current education system.

5.2.2. Extended Reality (XR) in Skill-development

The second half of the survey was focused on the possibilities of extended reality (XR) in skill development. In many cases, students cannot practice certain procedures on phantom models

or one another, but they must do it on a real patient. In these situations, they often feel the pressure that their actions can affect the health and well-being of the patient. Also, they may fear being judged by supervising clinicians. 39 of 52 respondents (75%) agreed at some level that practising these scenarios in a virtual place before on real patients would decrease their stress levels.

At the same time, as students currently are not able to practice most of the procedures at home, the students have to practice during the classes and the professor has to give immediate feedback. However, as there are many students in a class, it is difficult for the professor to pay attention to everyone. The professor can compare the students' results to each other's; however, it is difficult to receive feedback on personal improvement as there is not enough capacity. This explains why 48 respondents agreed/somewhat agreed that receiving objective feedback compared to the previous attempt - which is possibly when using virtual reality (VR) tools - could be beneficial. Table 6 and Figure 6 below visualizes the responses from the quantitative research.

Table 6 - Collected Quantitative Data from Surveys

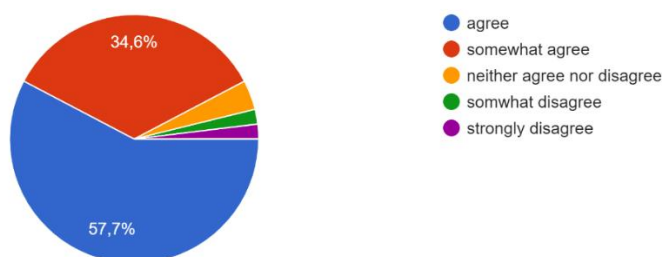
	Percentage of respondents	Number of respondents
Agree	57,7 %	30
Somewhat agree	34,6 %	18
Neither agree nor disagree	3,8 %	2
Somewhat disagree	1,9 %	1
Strongly disagree	1,9 %	1

Source: Own Research

Figure 6 - Collected Quantitative Data from Surveys

I believe that getting objective feedback on how I perform in virtual medical simulations, compared to my previous attempts, would be helpful.

52 válasz



Source: Own Research

In this way, students could better follow their development and if they feel a bit left behind, could practice more at home, hence it can also lead to better results in the exam. In addition, virtual reality (VR) also can be used to practice procedures on different patients and different tissue types which can be interesting for instance for blood vessel puncture. 36 students agreed and somehow agreed that these virtual simulations can prepare them for real-life situations.

Moreover, many times students suffer from practising sutures, many times they practice at home on a banana skin, however, it takes a lot of time to learn the right angle especially if no professor can correct them. 45 out of 52 students responded that it would be helpful to have visual guidance of augmented reality (AR) such as the correct angle while practising or performing. It wouldn't just improve their skills better, but it would decrease the number of errors and unsatisfied patients. Of course, usually during surgeries the suture is the least crucial part, however, it will be seeable on the patient forever, hence it is important for them that it is not just functional but aesthetic as well. Another visual help of augmented reality (AR) goggles is that CT and MRI scans can be projected over the patient and body parts, and according to 42 of the survey takers, it could help them better understand potential medical issues. Normally doctors have to put the medical images and the symptoms together in their hands to find the right diagnosis.

Besides, numerous special surgeries are extremely rare and advanced knowledge is needed to perform them. However, sometimes it is not possible to bring the patient from one hospital or one country to another. In these situations, virtual reality (VR) can provide unique solutions to plan and go through the surgery with a specialized professional who is located on the other side of the World, also any other professional who is interested in the topic could follow the surgery in the virtual environment. 47 of the medical students remarked this opportunity advantageous as they could visually follow and understand the process step by step. This type of telemedicine, distant learning could prepare professionals for unexpected situations and deepen their knowledge in specialized areas. The Table 7 and Figure 7 below visualizes the responses from the quantitative research.

Table 7 - Collected Quantitative Data from Surveys

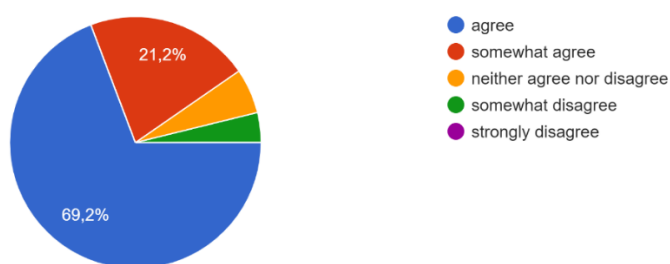
	Percentage of respondents	Number of respondents
Agree	69,2 %	36
Somewhat agree	21,2 %	11
Neither agree nor disagree	5,8 %	3
Somewhat disagree	3,8 %	2
Strongly disagree	0 %	0

Source: Own Research

Figure 7 - Collected Quantitative Data from Surveys

I believe it could be advantageous to participate in or witness special surgeries or medical procedures in a virtual environment, if they're occu...ly follow and understand the process step by step).

52 válasz



Source: Own Research

6. Conclusion

The qualitative and quantitative research indicated that by implementing virtual reality (VR) and augmented reality (AR) tools into a variety of medical training, the efficiency and quality of healthcare can be improved in terms of reduction of human errors, complications, re-repeatable surgeries, amount of costs, and improving the wellbeing of both patients and professionals in the medical field. The results of the research also indicate that the further benefits of extended reality (XR) depend on how rapidly the technology can be improved in terms of accuracy and sensitivity. According to the findings collected from the interviews and administered survey, the key quality and efficiency improving perspectives of extended realities in healthcare in Hungary are presented as follows:

In the first year of university medical students have anatomy courses where besides attending seminars, where they can see the anatomical structures on the cadavers, students need to memorize a huge amount of learning materials from atlases that only contain two-dimensional drawings of body parts. Because of this, many students find the anatomy course challenging, and around half of the students even drop out of medical school, already in the first year,

because of this course. By integrating augmented reality (AR) tools into anatomy training, students would be able to see the anatomical structures in a three-dimensional view, even when studying at home as smart devices can be used as augmented reality (AR) displays. In addition, during the seminars students could simultaneously practice on cadavers and in augmented reality (AR) goggles. In this way, besides seeing for instance the location of the arteries on the cadaver, students could see the inner structure of the arteries in the augmented reality (AR) goggles.

Furthermore, as all the respondents commented, medical professionals need continuous skill training and their learning curve is quite slow, especially in the beginning, as they have to practice even “simple” procedures for years before performing them without supervision on patients. During the practising period, professors have to supervise each student while also correcting them and giving them feedback, which is quite overwhelming. By implementing extended realities (XR) in skill training, students could have visual guides while practising and could receive continuous feedback about their progress in skill development.

The adoption of extended reality (XR) technology can help students learn, practice the materials, and master skills in a much shorter time than previously. Also, the adoption of new technology would decrease the number of dropout students, while also helping the professors not only in providing feedback but also in keeping the student’s attention. In this way, extended realities (XR) would make the learning and practising of medical students more efficient and could increase the quality of medical training. Also, in the long run, it would make healthcare overall more efficient, as more medical students would graduate from medical programmes, with an additional number of new doctors entering hospitals, hence more patients could be treated.

It is often said that people tend to make more mistakes when they feel stressed or anxious, and currently many professionals do their first practices on real patients, which makes the possibilities of human error quite high, both because of their missing experience and their high stress level. By providing an opportunity to practice life-like scenarios in a virtual environment, healthcare professionals would be more prepared and less stressed when facing surgery situations in real life. Higher skill levels would also improve patient experience, as a result, the overall quality and efficiency of healthcare would be higher.

During visits and surgeries, many times CT and MRI scans are needed to make the proper diagnosis and treatment. However, the doctors always have to switch between looking at the

patient and looking at the screen which shows the medical images, which takes a lot of time. By wearing extended reality (XR) goggles, doctors could see the CT and MRI scans projected over the patients which could help them better understand the problem and start the treatment as well as save time. Besides, wearing the goggles during surgeries can be advantageous as they can show visual guides, such as “dotted lines” for cutting, which would make the surgeries more precise. Moreover, the software of extended realities (XR) can alert the doctors of any unknown object in the patient before closing the wounds, hence preventing certain human errors. In this way, extended realities (XR) can prevent possible medical malfunctions and reduce the number of secondary surgeries. The adoption of emerging technologies by hospitals would lead to cost savings for hospitals, as certain surgeries do not have to be repeated, hence resources can be retained, with a lower risk of legal actions against hospitals because of medical malpractices. Furthermore, the quality of the healthcare services would improve as more surgeries would be successful even at the first time, hence more patients would receive treatment than before during the same period, and in this way, more human lives would be saved.

Using virtual reality (VR) for telecommunication and telemedicine can further improve the efficiency and quality of healthcare. Professionals would be able to help patients in distant, rural areas where advanced medical care is not available. Also, doctors could plan and practice surgeries in a virtual environment, even if they are not physically at the same place before the surgeries which would make them more prepared for any possibilities. Furthermore, rare operations could be done with the assistance of specialists from other countries, who have experience in the specific surgery or treatment and can help the surgeon step by step through the whole surgery. Additionally, doctors from all around the world could follow these operations from a virtual place and in this way, they could advance their knowledge in particular fields before facing similar situations the first time. This could be extremely beneficial for residents and professionals in later-stage skill training and would contribute remarkably to the quality of health institutions.

All things considered, extended reality (XR) technologies would significantly improve healthcare provision in Hungary from university floors to the most special surgeries and treatments. These technologies would increase the number of graduate doctors and would ensure that they have a deep knowledge and understanding both in the theoretical and practical fields. Furthermore, it would decrease the costs of healthcare provision to the whole society and thus budget deficits too. Additionally, the expenses of hospitals would decline as well,

especially as legal and medical malpractices could be prevented. Compared to the legal costs of hospitals, the price of extended reality (XR) tools is negligible, hence even with the initial investment of the technology overall it would lead to a decrease in expenditure. In the long run, a higher number of patients could be treated which would be essential, considering that Hungary has an ageing population and there is a continuous increase in demand for healthcare services.

It is appropriate to underline specific limitations of the diffusion of researched technologies in medical training. For instance, for smaller health institutions, especially in rural areas, extended reality (XR) tools are not yet affordable and fully accessible. Moreover, the adoption of extended reality (XR) technology is conditioned on diffused technical knowledge and openness towards technology adoption, which can be a barrier to adoption by older healthcare professionals. In addition, the use of researched technologies can raise certain ethical considerations, especially regarding data privacy, given the current absence of regulations governing their use.

Also, as extended reality (XR) technology has already been implemented in various healthcare institutions in the United States, there are limited results on the short-term effectiveness of research technologies, which are quite promising. Last but not least, as there is no long-standing record of the potential consequences of the adoption of extended reality (XR) technologies in medical training, further research and clinical trials are needed to have a comprehensive analysis that will validate the efficiency and quality aspects of emerging technologies.

7. Summary

The focus of my paper is emerging technology-driven product and process innovation in medical training. The improvements in display technology and extended reality (XR) technology - which combine digital and real environments - provide a more engaging learning experience. Extended reality (XR) is an umbrella term for immersive technologies: virtual reality (VR), augmented reality (AR) and mixed reality (MR) technology. These emerging technologies provide an experience either by combining the real world with a virtual world or creating a completely virtual reality. Extended reality (XR) technologies can be adopted in medical training, for instance, in anatomy learning, skill development and surgeries. The extended reality (XR) technology enables students and healthcare professionals to practice in simulations that stimulate all the senses (listening, reading, and seeing) and provide continuous feedback on personal skill development.

Due to the limited research on the adoption of integrating extended reality (XR) technologies into medical training, and with a majority of resources originating from the United States, my objective was to explore this topic within the Central and Eastern European region, especially in Hungary. The primary objective of this study was to investigate how extended reality (XR) technologies can improve the efficiency and quality of healthcare.

This research combined a methodology of collecting primary quantitative and qualitative data. The primary research methodology of my paper involved qualitative data collection through conducting semi-structured interviews with industry practitioners. In the secondary research, quantitative methodology involved administering a survey to validate the propositions of the qualitative research.

The sample of the qualitative research consisted of 6 entrepreneurs with various backgrounds, and each interview was conducted online and lasted about 25-40 minutes. The follow-on quantitative research was conducted through an online survey which collected 52 full observations from Hungarian medical students.

Both qualitative and quantitative research findings indicated that integrating virtual reality (VR) and augmented reality (AR) tools into medical training programs can enhance the efficiency and quality of healthcare services. By implementing extended reality (XR) technologies into medical training, more medical students would graduate from medical universities, hence more doctors would practice at hospitals and more patients could be treated. Additionally, the quality of the healthcare services would improve as more surgeries would be successful even at the first time, hence more patients would receive treatment than before during the same period.

Furthermore, the adoption of emerging technologies would reduce the healthcare costs for society as a whole, resulting in decreased budget deficits. This adoption would also lower hospital expenses, particularly by preventing legal and medical malpractice issues. Over time, a higher number of patients could receive treatment, which is crucial given Hungary's ageing population and the ongoing rise in demand for healthcare services.

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Appendices

Appendix 1: Visualization of extended realities (XR)

a)

Augmented reality (AR) to project 3D visuals over 2D atlases



Source: Image credit: The Human Anatomy Atlas app (<https://geence.ar/webar-is-powering-a-new-era-of-interactive-education/>)

b)

Virtual reality (VR) to practice surgeries in a virtual environment



Source: Fundamental VR (<https://vstream.ie/st-georges-university-hospital-introduces-vr-surgical-training/>)

Appendix 2: Interview Protocol Matrix for Qualitative Research

	Background information	Theme 1: There are benefits of leveraging new technology in healthcare	Theme 2: New technology can be integrated into professional training processes
Opening interview question			
Interview question 1: You have spent “x” number of years in a healthcare context, exploring various uses of Virtual Reality and Augmented Reality. What has motivated you to explore the role of Virtual reality and Augmented reality tools in professional training?	X	X	
Key interview questions			
Interview Question 2: In your opinion, what are the specific benefits of implementing Virtual Reality and Augmented Reality technologies in professional training?		X	
Interview Question 3: Can you explain how Virtual reality and Augmented reality technologies have improved the quality of healthcare services? Follow on: In what ways have these technologies contributed to the development of skills among medical students and professionals?		X	
Interview Question 4: In your experience, how have Virtual Reality and Augmented Reality technologies helped make training processes more efficient?			X
Interview Question 5: How do you measure the effectiveness of Virtual Reality and Augmented Reality technologies in skill development?			X

Appendix 3: Qualitative Observations

Thematic coding of qualitative research	Codes	respondent 1	respondent 2	respondent 3	respondent 4	respondent 5	respondent 6
You have spent "x" number of years in a healthcare context, exploring various uses of Virtual Reality and Augmented Reality.							
Interview question 1: What has motivated you to explore the role of Virtual reality and Augmented reality tools in professional training?	6						
1.1. Medical background	4						
surgeon	2	Y	spent many years	Y	As a surgeon 10		
dentist	1					Y	Studied Dental Me
anatomy professor	1				Y	He is doing phd a	
1.2. Engineer	1			Y	Studied Engineerin		
1.3. Economist	1					Y	learned econo
1.4. curiosity about the new technology	4	Y	His openness and	Y	. However, after th	Y	she met with th
1.5. already used the technology in other field	2		Y	as a male used it			Y
Interview question 2: In your opinion, what are the specific benefits of implementing Virtual Reality and Augmented Reality technologies in professional training?	6						
2.1. Telecommunication	1	Y	new doctors wish				
2.2. Anatomy learning	5		Y	we do have 2dim	Y	3d visualization o	Y
replacing cadavere	2		Y	instead of cadav		Y	replacing cadav
2.3 Skill training	4	Y	Can simulate diffe	Y	as a medical pro	Y	precise proced
wellbeing of learner	1					Y	situational train
2.4. Complications	2		Y	the patients wou	Y	prevention of dan	
2.5. surgeries	3				Y	check the patient	Y
2.6. Cost	1			Y	It is cheaper		
Interview question 3: Can you explain how Virtual reality and Augmented reality technologies have/ can improved the quality of healthcare services?	6						
3.1. Skill training	3	Y	Continuous medi	Y	Skill trainings it is		Y
3.2. Surgeries	2		Y	more precise an		Y	precise certain
3.3. Complications	2		Y	tumors for exam		Y	significantly de
3.4. Cost	2		Y	preserving a lot o		Y	decrease the co
3.5. Telemedicine	2			Y	telecommunication		Y
3.6. Not yet implemented on that level to be certain	1				Y	this	
Follow on: In what ways have these technologies contributed to the development of skills among medical students and professionals?							
3.1. Skill training	5	Y	are only two medi	Y		Y	surgical --> impro
wellbeing of learner	2	Y	they feel stressed				Y
using the technology	1	Y	Far better unders				
view							
practicing students	1					Y	every student c
overprojection	1						Y
learning curve	3		Y	in the beginning	Y		
3.2. Surgeries	1		Y	in certain surger			
3.7. Patient	1		Y	the patient wou			
3.3. Complications	1		Y	if you have just a			
3.8. Feedback	1						Y
Interview question 4: In your experience, how have Virtual Reality and Augmented Reality technologies helped make training processes more efficient?	6						
telemedicine	1	Y	provide teamwo				
learning curve	5		Y	previously just s	Y	efficiency as for m	Y
feeling	1		Y	subjective how t		Y	help students im
Interview question 5: How do you measure the effectiveness of Virtual Reality and Augmented Reality technologies in skill development?	6						
comparison	4	Y	there is an imple	Y	It is not easy to fi	Y	loads of data ne
accuracy of technology	2			Y	accuracy especial	Y	It related problem

Appendix 4: Survey Questions

Please answer the following questions by selecting yes or no as answers.

1. Have you studied at a Hungarian medical university or are you currently enrolled at one?
2. Have you so far attended anatomy classes and its training sessions?

Please choose one of the options.

3. Which university have you attended/are you attending?

Please answer each of the following statements on a scale from strongly agree to strongly disagree.

(agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly disagree)

Thematic area	Variables	Statements
XR in anatomy learning	Use of technologies	I am interested in using Virtual Reality and Augmented Reality tools in education and training.
	Difficulties with anatomy	I find anatomy learning materials to be challenging during my medical studies.
	Difficulties with anatomy	I believe that using Augmented and Virtual Reality to visualize anatomical structures in 3D would enhance my understanding of anatomy and make my learning process faster.
	Practicing	I am willing to practice anatomical structures from home in a virtual environment using VR technology, in addition to traditional cadaver-based learning.
XR in skill development	Learner's performance	I think practicing medical procedures in a virtual environment before real-life patient encounters would reduce my stress and anxiety.
	Learner's performance	I believe that getting objective feedback on how I perform in virtual medical simulations, compared to my previous attempts, would be helpful.
	Additional information	I believe that using Augmented Reality goggles to overlay CT and MRI scans onto patients would assist me in better understanding potential medical issues.
	Additional information	I believe it could be advantageous to participate in or witness special surgeries or medical procedures in a virtual environment, if they're occurring in other parts of the World (as it allows me to visually follow and understand the process step by step).
	Precision	I think having visual guidance, such as the correct angle and

		pressure for stitching through AR goggles while performing the sutures, will improve my skills.
	Precision	Practicing medical procedures, like blood vessel puncture, on different tissue types in a virtual environment will help me prepare for different real-life scenarios.