Augmented reality applied to health sciences: a literature review

Realidad aumentada aplicada a ciencias de la salud: una revisión de literatura

J. D. Parra-Quintero C. A. Mueses-Erazo

DOI: 10.22517/23447214.25528

Artículo de investigación científica y tecnológica

***Abstract*— The integration of augmented reality (AR) technology worldwide has been pivotal for advancements across various sectors. Its accessibility and availability are fundamental to technological evolution. This paper presents a literature review on the applications of AR in health sciences, highlighting its main contributions and advancements in this field. To assess the level of attention from the scientific community, three search algorithms were employed using the Scopus database with relevant keywords and a historical range extending to the present. The search was restricted to review, research, and conference articles. The results indicate a growing and profound interest from the research community in exploring the role of AR in health sciences over recent years.**

***Index Terms*— augmented reality, health sciences, literature review, search algorithm, database.**

***Resumen*—La inclusión de la tecnología de realidad aumentada (AR, por sus siglas en inglés) a nivel mundial ha sido crucial para el desarrollo de muchos sectores, su accesibilidad y disponibilidad es fundamental para la evolución tecnológica. Este documento presenta una revisión de literatura acerca de AR en las ciencias de la salud, sus principales contribuciones y avances en el campo de estudio. En ese sentido, para indagar sobre la atención de la comunidad científica hacia este tema; se emplearon tres algoritmos de búsqueda a través de la base de datos Scopus mediante palabras clave y años desde la historia hasta la actualidad. La búsqueda se limitó a artículos de revisión, investigación y conferencias. Los resultados demuestran que durante los últimos años ha habido un profundo interés por parte de la comunidad de investigadores para indagar acerca de AR sobre las ciencias de la salud.**

***Palabras claves*— realidad aumentada, ciencias de la salud, revisión de literatura, algoritmo de búsqueda, base de datos.**

I. Introduction

The augmented reality (AR) has been a fundamental part of the important technological revolution, which positions it as a digital tool of great projection worldwide. Its incorporation in various activities of education, medicine, automotive, architecture and design, training and simulation, make it a complementary form of learning and entertainment for society. AR has been applied in oral health processes [1], astronaut mental health and space tourism [2], training and education in plastic surgery [3], as well as in the manufacturing industry [4], gaming and entertainment [5].

This tool holds great potential in the health sciences sector and is expected to have a promising future in medical and biomedical education and training [6], [7]; allowing students and healthcare professionals to visualize and practice procedures in virtual environments to improve their understanding and skills in the relevant competencies, facilitating the cooperation of professionals in different parts of the world.

This technology can even facilitate communication between doctors and patients by visualizing data in a more understandable and accessible way, as well as providing personalized information and reminders about health care, medications, symptom monitoring and healthy lifestyle advice. However, it will be necessary to dig a little deeper into AR from its beginnings, main contributions and founded hopes for its contribution to health sciences.

Augmented Reality (AR) is an innovative technology that seamlessly blends virtual and real elements, creating an interactive and immersive experience [8]. In health sciences, AR implementation has unlocked numerous opportunities for enhancing medical care, advancing professional training, and empowering patients.

This technology enables the projection of digital information, such as images, graphics or three-dimensional models, onto the real physical environment, providing users with an immersive experience that improves the understanding of complex medical concepts [9]. It also contributes significantly in different academic aspects such as: i) improving the visualization and understanding of medical information, allowing health professionals and patients to interact with three-dimensional models of organs, tissues, and systems of the human body [10], ii) medical education and training to offer through AR great possibilities of education and training to health care professionals [11], improving patient participation to actively involve patients in their own health care through the use of technological applications and devices, iv) access to relevant information about specific diseases, drugs or treatments, allowing people to understand their current condition and make informed decisions, v) improving the visualization of the expected effects of a treatment or procedure, facilitating

This manuscript was submitted on February 29, 2024. Accepted on November 21, 2024. And published on December 20, 2024.

patient-physician communication and increasing patient confidence in the plan of care [12].

Through this work, an analysis of existing research on AR in the field of health sciences was carried out, its scope is limited to the main research, conferences and reviews and analysis documents were located through the Scopus platform. It is for this reason that this article presents the main contributions and advances of AR in health sciences, details its main applications since its beginnings, and reports relevant research within the discipline. The second section presents the materials and methods used to perform the bibliographic analysis using the aforementioned database. In the third part, the results of the search are highlighted and the main contributions of AR to the health sciences, especially bioengineering, are discussed [13]–[15], medicine [11], [16], nursing [17], [18], oncology [19], clinical psychology [2], [20], [21], and dentistry [22], [23].

In the following section, a literature review is conducted using three search algorithms, which comprise the role of AR on health sciences.

II. Materials y methods

A. Data source and search strategy

There are currently various tools for searching scientific information, including PubMed, UpToDate, ScienceDirect, Web of Science (WOS), and Scopus. The latter has been the most widely used repository of information as a method to find scientific information, which has been widely used for the dissemination of new knowledge [21], [24].

For this purpose, three search algorithms were implemented within the referred database. For the first, the code [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences)] was used, where keywords associated with augmented reality applied to health sciences were taken into account. For the second and third search algorithms, the search criteria [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019))] and the criterion [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "cr")) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019))], respectively. The difference between the second and third algorithms is that within the exploration process using the data platform; all documents are restricted to the last five years (second algorithm), and also, to only review, conference and research type documents (third algorithm) for those same last five years.

III. Results and discussion

In this section, the results of the three searches that were performed are shown. Then, a report is made, and, finally, the interest of the scientific community in applied AR studies in health sciences is discussed.

A. Preliminary approaches

In the first search, [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences)], 254 documents were found from 2003 to 2023. The United States is the country with the highest number of published papers (50), followed by Australia (25), and finally Spain (23). Figure 1 shows the number of related documents published per country, highlighting the top 10 globally.

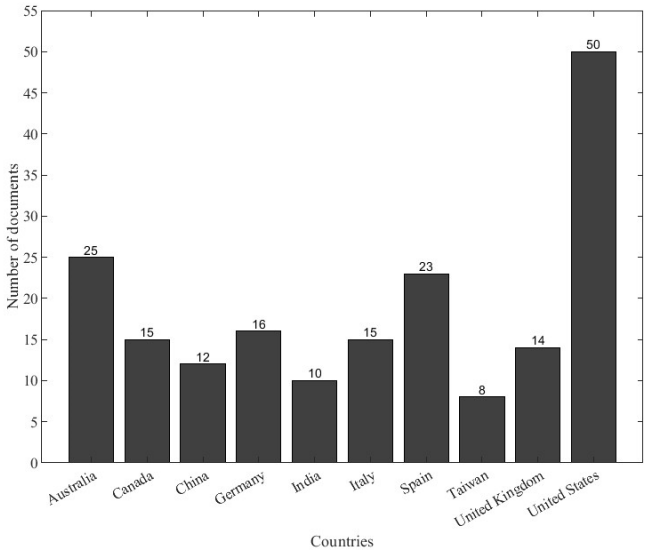


Figure 1. Number of documents by country for the first search algorithm. Source: own elaboration.

The Figure 2 represents the countries reported using the second search algorithm through the code [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019))], in that sense, about 190 resolved documents were obtained from the year 2019 to 2023. The United States is the country with the highest number of published papers (39), followed by Australia (18), and finally Spain (17). Although the same top 3 as in the first algorithm is maintained, it is important to clarify that the total number of documents tends to decrease due to the discretization of the search by means of the filter of the last five years.

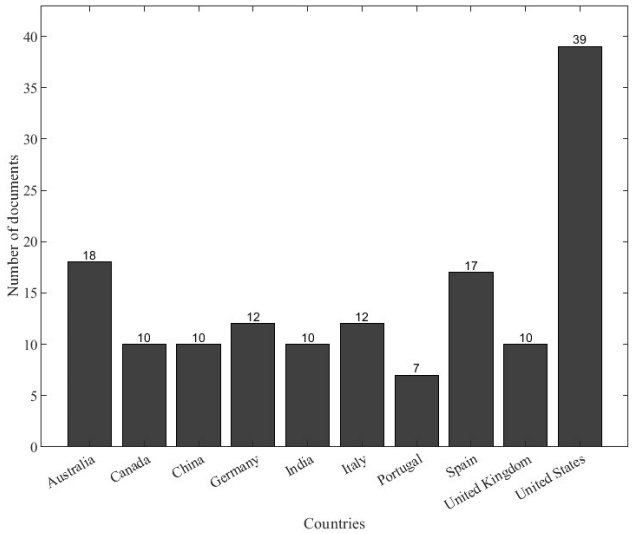


Figure 2. Number of documents by country for the second search algorithm. Source: own elaboration.

In the third search [TITLE-ABS-KEY (augmented AND reality AND in AND health AND sciences) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "cr")) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019))], 151 solved papers were found from 2019 to 2023 limiting the algorithm in research, review and conference articles. The Figure 3 represents the rest of the countries placed in the top 10, as can be seen, the three countries that topped the list now were the United States (29), Germany (13) and Australia (12).

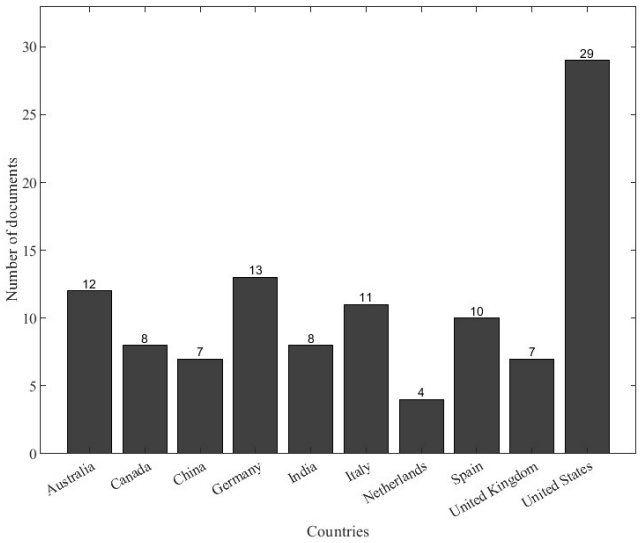


Figure 3. Number of documents by country for the third search algorithm. Source: own elaboration.

To compare the number of documents published by country, a graph was generated for each of the three algorithms, illustrating publication trends over the last few years. The Figure 4 shows the number of documents published per year for the three search algorithms used in Scopus. It can be seen that during the last few years, the scientific community has shown a strong interest in studying AR in health sciences; and that the third algorithm is the one that shows the greatest upward trend in the number of documents published during the last five years, with about 63 documents published.

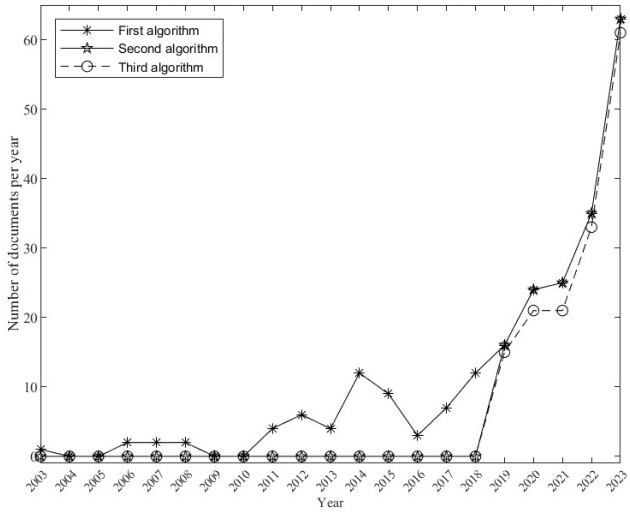


Figure 4. Number of documents per year for the three search algorithms used. Source: own elaboration.

The Figure 5 shows the distribution of publications according to the type of documents filtered and reflects the classification of publications obtained through the third algorithm, which is the most restrictive and has the types of documents on which this research was based.

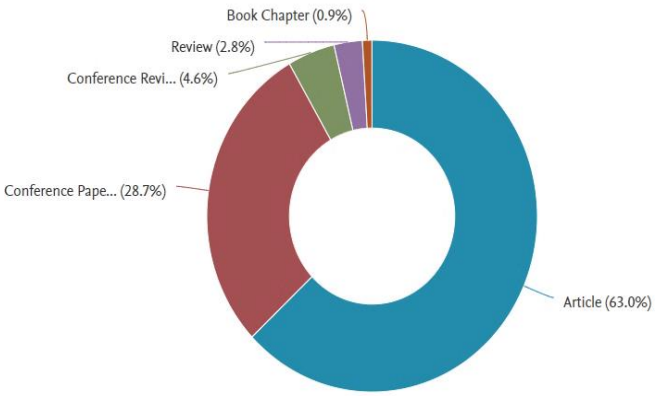


Figure 5. Number of publications obtained using the third algorithm. Source: Scopus.

As highlighted in the introductory section, while AR can span several disciplines; this paper was focused on the health field, particularly in areas such as:

B. AR in medicine

In the area of medicine, various applications have been made in surgery and procedures, such as real-time virtual guides and

images where surgeons can use AR devices to overlay preoperative images, localize anatomical structures, and make more precise incisions. This technology can help display vital information about the patient, such as monitoring vital signs during the procedure being performed [9].

As pointed out by A. Ibañez et al. [25], AR has the potential to bring several benefits to the healthcare field through education and training, providing an interactive and practical way to guide students and professionals in this discipline through the visualization of 3D anatomical models, simulations of medical procedures, and real-time virtual training. The above, could contribute to improve the accuracy and efficiency of procedures in the health sciences, and help, in the navigation of minimally invasive surgeries, such as those studied by Balla et al. [26]. Another area is the improvement of diagnostic accuracy, as AR can help medical staff during the initial assessment; by providing additional information about patients, overlaying relevant medical data using MRI or CT images. In the field of view of physicians, it would enable them to acquire a more complete understanding of the patient's condition and make better decisions. On the other hand, the inclusion of AR in health sciences, allows to contribute in the area of rehabilitation and therapy, since in that sense, it helps patients to recover from injuries, diseases or disabling conditions. See Figure 6.

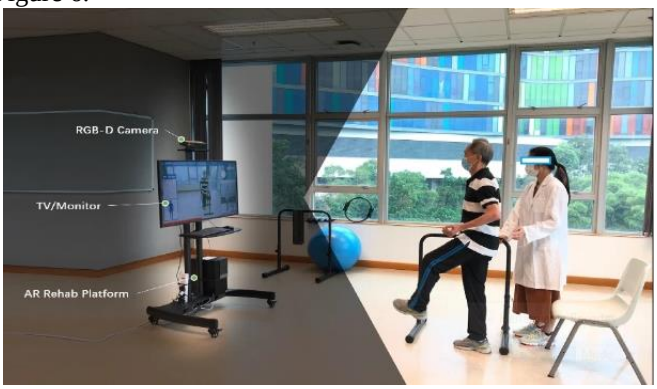


Figure 6. Rehabilitation process in a patient who had COVID-19. Source: [27].

Yang et al. [27] developed an Augmented Reality Rehabilitation System (ARRS) to incentivize virtual training and decrease the rate of personal contact between individuals. They found that through ARRS, personnel can be effectively trained without further contact where the effort of medical professionals is significantly reduced.

For example, M.F. Pereira et al.[28] made a systematic review of the role of AR on hand rehabilitation, since it has been considered to be the most frequently injured part of the human body [29]. Figure 7 exemplifies the hand rehabilitation process in a patient.

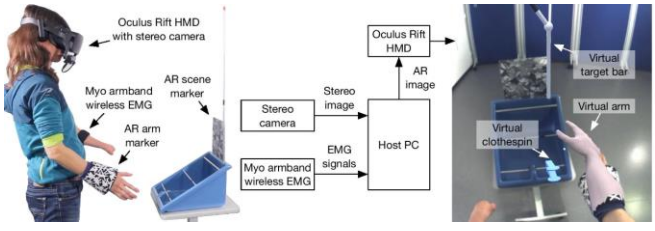


Figure 7. Experimental process of hand rehabilitation in a patient. Source: [30]

J.A. Acevedo et al. [31] carried a review of robotic rehabilitation technologies in children with upper limb injury, within the most relevant technologies are: i) RobotInMotion for cerebral palsy intervention, ii) instrumented glove for neurological injuries and upper limb injuries, ii) AR-based table tops, to treat hemiplegia.

Moro et al. [32] studied the importance and great potential of using AR to improve the process of knowledge acquisition in physiology and anatomy. To do so, the authors compared an intervention in which they had 38 participants before and after; using and not using Microsoft HoloLens. It was found that in addition to the fact that AR can contribute positively to learning interventions, it also contributes to a significant increase in dizziness causing other adverse health effects, such as nausea, disorientation or fatigue, which poses a threat to people with sensitivity to AR instruments.

Kan Yeung et al. [16] conducted a literature research on the scientific literature addressing the topic of applied AR in health sciences, focusing on literature related to the use of virtual reality (VR) as a basis for using AR to contribute to medicine with topics such as evaluation of surgical procedures, neurosurgery, and pain management. Vles et al. [33] conducted a scientific investigation in which they consulted on studies or papers covering the topic of how AR can contribute in the preoperative processes of plastic surgery. In this they took into account postoperative planning, use of augmented reality in preoperative processes, technical precision, operative time, complications and costs of the total intervention. Mehta et al. [34] pointed out that there are several fields of application of AR in emerging health: i) surgeries, ii) neurosurgeries, iii) orthopedic surgery, iv) laparoscopic surgery, v) electrocardiography, vi) head and neck surgery, vii) ultrasound, among others. The authors stated that AR, unlike VR, has a more realistic environment, so that some physicians using this tool could contribute to reducing the number of deaths in sick people by trying a treatment before doing so.

Sumdani et al. [35] conducted a systematic study in which they collected, analyzed, and interpreted how through AR can be implemented adjunctively in spine surgeries. This work performed an analysis of the available literature using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to ascertain the relevant contribution to spine surgery in living individuals. AR was found to be a significant tool for improving the understanding of the surgical procedure.

Ghaednia et al. [36] conducted a study that was based on providing spine surgeons and clinical researchers with general information about the current applications, future potentials, and accessibility of augmented reality systems in spine surgery. In this research, the study was covered focusing on technological items, applications in surgery, spine training, and orthopedics.

C. AR in nursing

The insertion of AR in nursing could become feasible. According to H. Wuller et al. [17], most research has been based on pilot schemes where AR tools such as glasses, tablets and smart watches are used, allowing them to practice procedures in virtual environments that simulate real-world situations. Among the advantages noted are the increase in the quality of medical care and efficiency, procedural accuracy and time optimization.

D. Bliss et al. [18],]carried out a study to improve nursing education on pressure injuries, by means of a pilot evaluation survey, the study was carried out, for this purpose, the sample was represented by about 32 members of which 27 were nursing students and 5 were teachers. In that sense, a prototype of a Projected Augmented Reality (P-AR, which incorporates 3D dynamic images) system was used to see how it affected the learning process of the people who participated in the survey. In the findings, it was observed that P-AR is an innovative tool and has a significant effect on students' learning about pressure injuries.

Rodríguez et al. [37] studied the influence of AR on learning for lower limb ulcer care. The study approach was quasiexperimental and was done with 137 nursing students who were divided into two groups: the first had the traditional teaching methodology, the second involved augmented reality as a methodological source used for teaching. The students performed the AR experience (HP Reveal® and Aumentaty Creator®) using their own electronic devices (smartphones or tablets). The researchers statistically analyzed the data using Statistical Package for the Social Sciences (SPSS) and verified the assumptions of normality, independence and homoscedasticity, as well as the analysis of variance (ANOVA). Among the results, students stated that AR facilitated the understanding of lower limb ulcer management, and that it not only improved health knowledge, but also students' skills, perceptions and expectations towards the teaching-learning process.

The Figure 8 depicts an augmented reality experience to contribute significantly on the academic training of students in the field of health sciences, as reported in [38].

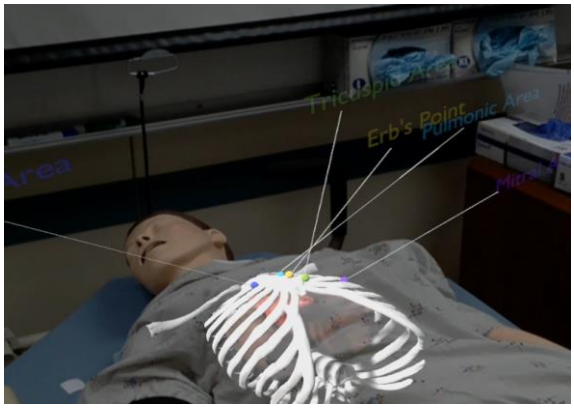
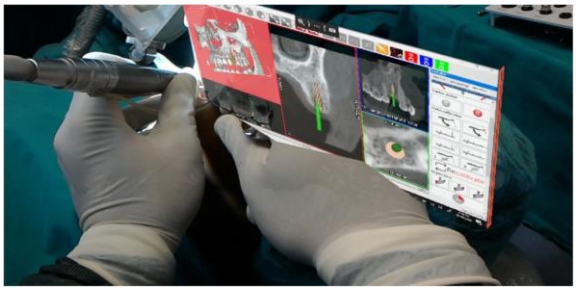


Figure 8. Augmented reality experience to improve student education. Source [38].

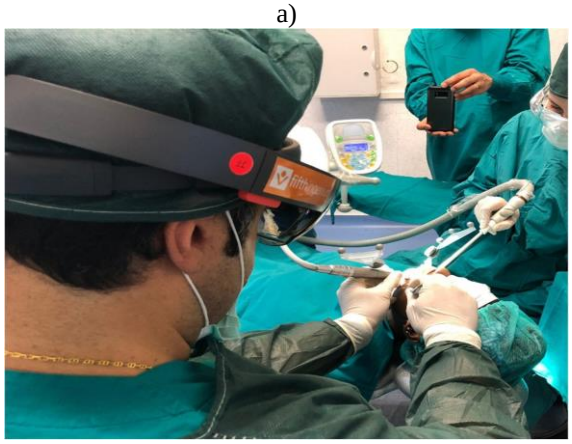
D. AR in dentistry

In the field of dentistry, AR has played a pivotal role in dental treatment planning [39], [40], visualization of radiographs [41], [42] and, training and education [43], [44].

Innocente et al. [45], reported the use of AR in the field of dentistry, as well as in dental education and contemporary knowledge, the authors conducted a comprehensive literature review, where the authors considered the following information platforms: PubMed, Scopus, WOS and Google Scholar. Among the results, 168 articles were found during the first search, of which 20 were chosen for review. It was discovered that AR and artificial intelligence (AI) are useful for clinical practice, with the aim of optimizing students' learning during preclinical education; they also demonstrate that dentists can use these tools to show their patients the expected results before undergoing dental procedures. Another advantage lies in the pediatric population as it helps to avoid phobia of dental procedures, however, they conclude that there is a lack of studies that focus on technological standards with high quality data in the field of dentistry.



a)



b)

Figure 9. Surgical procedure supported by means of AR goggles. Source:[22].

Fahim et al. [23] pointed out that there is a good relationship during recovery from problems in patients through the interaction between human-computer, which contributes to mood and behavior. According to the referred authors, a different environment such as AR satisfies the need of the patient who is in an abnormal mental situation or condition.

E. AR in bioengineering

In the field of bioengineering, AR could have the potential to offer several significant advantages in terms of design, research, training and medical care. In that sense, in this discipline, there are great contributions through AR in the design of medical devices [46] and training of biomedical engineers [7], [13], [47], among many other things.

Condino et al. [13], conducted a review of the main AR tools used and strongly driven by the technological evolution of biomedical engineering and robotics in vascular and endovascular surgery. It was found that AR tools such as headmounted displays (HMD), goggles, spatial projection displays, smartphones and micro projectors are widely applied in catheter navigation, abdominal aortic aneurysms (EVAR), retrograde peroneal access, groin incision guidance, lower limb angioplasty, among others. This paper highlighted the benefits of AR technology that connects both patients and surgeons.

Eldaly et al. [14]] performed a comprehensive analysis of the scientific literature about AR in phantom limb management, they used databases as sources of information from EMBASE, Cumulative Index to Nursing and Allied Health Literature, PubMed and WOS, they performed an initial search that yielded 164 results of which; they chose 9 studies, one study was of good quality, while 8 were of fair to medium quality, of these 7 studies used VR, and 2 used AR, the number of sessions varied between 1 and 28, with time intervals between 10 minutes and 2 hours, the scales they used to assess pain were, the numerical rating scale, the pain rating index, the McGill pain questionnaire and the visual analog scale, all studies reported an improvement in the pain caused by phantom limb syndrome, however, they highlight that most studies have a poor design, so there is a lack of evidence to recommend them in the management of phantom limb syndrome.

Barteit et al. [15] conducted a systematic literature review of AR-based head-mounted devices (helmets) for medical education, the advantages of which are that they allow repetitive practice without adverse effects to the patient in various medical disciplines and can introduce new ways of learning complex medical content, as well as alleviate economic, ethical, and supervisory constraints on the use of traditional medical learning materials, such as cadavers and other skills laboratory equipment. The selected databases were: Cochrane Library, WOS, Science Direct, PsycINFO, Education Resources Information Centre, PubMed, and Google Scholar, in most studies it was found that the use of these devices were effective in medical education for certain skills and knowledge, while other studies suggested it only as an additional teaching method, in that sense, it is concluded that to generate relevant evidence in the future it is necessary to evaluate the devices with the different types of reality, to analyze strengths and deficiencies.

F. AR in oncology

In oncology, AR has been playing a relevant role since it could contribute in the diagnosis, treatment and care of individuals affected by cancer, in that sense, it has served to locate tumors of breast cancer [48], and its visualization [49], as well as for performing breast biopsies by ultrasound assisted by AR [50], interventional oncology [50], which, focuses on the use of minimally invasive medical procedures for the diagnosis, treatment and management of oncologic diseases [51].

Kok et al. [19] conducted a review on personalized oncology education as a teaching program in radiation oncology (cancer treatment using ionizing radiation) by encouraging digital learning (DL). In this regard, the application of immersive DL tools in radiation oncology education was analyzed. The authors pointed out that AR could even be used in an unreal patient where the learner can see from an AR screen; visually strategic locations so that they know where they can perform oncology procedures. It can be inferred that AR will come to play an important role as a learning environment to meet the educational demand of oncology students.

G. AR in clinical psychology

While AR has been a fast-growing technological tool in entertainment and professional training, it has also been used for the treatment of psychological disorders [20], including AR therapy for depression [52]–[54], games for children with Autism Spectrum Disorders (ASD) [55], [56] and therapy for eating disorders [52]–[54].

Miles et al. [57] studied the role of AR in care settings for the elderly who may often face anxiety, depression and constant loneliness. In that sense, the authors made a detailed review of the topic in databases such as WOS, Medline CINHAL, Scopus, Embase and PsycINFO. It was found that through the use of AR it would be possible to address the barriers that generate critical mental health conditions.

Fahim et al. [23] pointed out that AR contributes to emotional improvement in the field of health, highlighting its fundamental usefulness in addressing mental health disorders. It is highlighted that this technological tool could eventually inhibit addiction and phobias in people through an AR environment.

Chen et al. [58]] conducted a comprehensive literature review regarding extended reality (XR) and telehealth interventions for children or adolescents with autism spectrum disorder, in which the following databases were considered; WOS, PubMed and Cochrane Library, in the studies the authors highlight that it was found that after the interventions, positive improvements were observed for participants with Autism Spectrum Disorder (ASD) in social interaction, acceptance and engagement. The authors also note that the studies found that after the interventions, positive improvements were observed for participants with ASD in social interaction, communication and speech, emotion recognition and control, daily living skills, reduction of problem behaviors, attention, cost reduction, reduction of anxiety symptoms, pretend play, contextual processing, matching ability and insomnia control, which provides solid evidence for extended reality as an intervention method for children and adolescents with ASD, however, they emphasize that further research and standardized outcome measures are required in the future to establish the therapeutic efficacy of the two interventions independently or in combination.

AR advances in multiple healthcare disciplines have demonstrated transformative potential. In the medical field, AR has improved medical image visualization and procedure planning, increasing diagnostic and therapeutic accuracy. In nursing, it has become a valuable tool for training and patient care, improving communication and efficiency. In dentistry, it has improved treatment planning and practitioner training. The trend suggests continued growth, with future emphasis on interdisciplinary collaboration and the expansion of AR in education and healthcare, thus driving more advanced, personalized and efficient services in the health sciences.

IV. Conclusion

The inclusion of the three search algorithms for scientific information through Scopus was fundamental to be able to know the trend of exploration by researchers about the role played by AR in the health sciences. By means of the first search algorithm, the main countries that have contributed most to the dissemination of scientific information were identified. For the three algorithms used, the United States was the country that has done the most to fill the existing gaps in knowledge on the subject of this article. The third search algorithm has been the most restrictive, and, therefore, allows providing scientific information characterized by conference, research and review papers of the last five years. Finally, the outstanding attention of the scientific community to this topic, evidenced by an exhaustive review in the database employed, highlights the great interest of researchers in exploring and understanding the possible health effects of AR. These findings highlight the growing research interest in AR, emphasizing its significance as a pivotal tool for advancing medical care and health education globally.

References

[1] W. Romalee, F.-T. Tsai, Y.-C. Hsu, M.-L. Hsu, and D.-H. Wang, "A mobile augmented reality-integrated oral health education for community dwelling older adults: A pilot study," *J. Dent. Sci.*, Jul. 2023, doi:10.1016/J.JDS.2023.07.019.

[2] S. Holt, "Virtual reality, augmented reality and mixed reality: For astronaut mental health; and space tourism, education and outreach," *Acta Astronaut.*, vol. 203, pp. 436–446, Feb. 2023, doi:10.1016/J.ACTAASTRO.2022.12.016.

[3] Y. M. Khoong *et al.*, "The application of augmented reality in plastic surgery training and education: A narrative review," *J. Plast. Reconstr. Aesthetic Surg.*, vol. 82, pp. 255–263, Jul. 2023, doi:10.1016/J.BJPS.2023.04.033.

[4] P. Balco, P. Bajzík, and K. Škovierová, "Virtual and Augmented Reality in Manufacturing Companies in Slovakia," *Procedia Comput. Sci.*, vol. 201, no. C, pp. 313–320, Jan. 2022, doi:10.1016/J.PROCS.2022.03.042.

[5] Z. Mahmood, T. Ali, N. Muhammad, N. Bibi, M. I. Shahzad, and S. Azmat, "EAR: Enhanced augmented reality system for sports entertainment applications," *KSII Trans. Internet Inf. Syst.*, vol. 11, no. 12, pp. 6069–6091, 2017, doi:10.3837/tiis.2017.12.021.

[6] J. C. Almenara and J. B. Osuna, "Augmented reality applied to medical education," vol. 18, no. 3, 2017, doi:http://dx.doi.org/10.1016/j.edumed.2016.06.015 1575-1813/©.

[7] M. Venkatesan *et al.*, "Virtual and augmented reality for biomedical applications," *Cell Reports Med.*, vol. 2, no. 7, pp. 1–13, 2021, doi:10.1016/j.xcrm.2021.100348.

[8] Telefónica Foundation, "Augmented reality: a new lens for viewing the world," pp. 19–22, 2019.

[9] C. E. O. Rangel, "Augmented reality applied in medicine," 2011. .

[10] IAT, "Augmented reality in medicine saves and improves lives," 2021. .

[11] J. Cabero Almenara, J. Barroso Osuna, and M. Obrador, "Augmented reality applied to the teaching of medicine," *Educ. Medica*, vol. 18, no. 3, pp. 203–208, 2017, doi:10.1016/j.edumed.2016.06.015.

[12] T. Rey, "Applications of augmented reality in medicine today," 2019. .

[13] S. Condino *et al.*, "Bioengineering, augmented reality, and robotic surgery in vascular surgery: A literature review," *Front. Surg.*, vol. 9, 2022, doi:10.3389/fsurg.2022.966118.

[14] A. S. Eldaly *et al.*, "Virtual and Augmented Reality in Management of Phantom Limb Pain: A Systematic Review," *Hand*, 2022, doi:10.1177/15589447221130093.

[15] S. Barteit, L. Lanfermann, T. Bärnighausen, F. Neuhann, and C. Beiersmann, "Augmented, mixed, and virtual reality-based head-mounted devices for medical education: Systematic review," *JMIR Serious Games*, vol. 9, no. 3, 2021, doi:10.2196/29080.

[16] A. W. Kan Yeung *et al.*, "Virtual and augmented reality applications in medicine: Analysis of the scientific literature," *J. Med. Internet Res.*, vol. 23, no. 2, 2021, doi:10.2196/25499.

[17] H. Wüller, J. Behrens, M. Garthaus, S. Marquard, and H. Remmers, "A scoping review of augmented reality in nursing," *BMC Nurs.*, vol. 18, no. 1, pp. 1–11, 2019, doi:10.1186/s12912-019-0342-2.

[18] D. Z. Bliss *et al.*, "Projected Augmented Reality (P-AR) for Enhancing Nursing Education about Pressure Injury: A Pilot Evaluation Study," *J. Wound, Ostomy Cont. Nurs.*, vol. 49, no. 2, pp. 128–136, 2022, doi:10.1097/WON.0000000000000858.

[19] D. L. Kok *et al.*, "Virtual reality and augmented reality in radiation oncology education – A review and expert commentary," *Tech. Innov. Patient Support Radiat. Oncol.*, vol. 24, no. September, pp. 25–31, 2022, doi:10.1016/j.tipsro.2022.08.007.

[20] C. Vinci, K. O. Brandon, M. Kleinjan, and T. H. Brandon, "The clinical potential of augmented reality," *Clin. Psychol. Sci. Pract.*, vol. 27, no. 3, pp. 1–14, 2020, doi:10.1111/cpsp.12357.

[21] P. J. McNicholas, R. G. Floyd, L. E. Fennimore, and S. A. Fitzpatrick, "Determining journal article citation classics in school psychology: An updated bibliometric analysis using Google Scholar, Scopus, and Web of Science," *J. Sch. Psychol.*, vol. 90, pp. 94–113, Feb. 2022, doi:10.1016/J.JSP.2021.11.001.

[22] G. Pellegrino, C. Mangano, R. Mangano, A. Ferri, V. Taraschi, and C. Marchetti, "Augmented reality for dental implantology: A pilot clinical report of two cases," *BMC Oral Health*, vol. 19, no. 1, pp. 1–8, 2019, doi:10.1186/s12903-019-0853-y.

[23] S. Fahim *et al.*, "Augmented Reality and Virtual Reality in Dentistry: Highlights from the Current Research," *Appl. Sci.*, vol. 12, no. 8,

2022, doi:10.3390/app12083719.

[24] S. D. Meyers, L. Azevedo, and M. E. Luther, "A Scopus-based bibliometric study of maritime research involving the Automatic Identification System," *Transp. Res. Interdiscip. Perspect.*, vol. 10, no. April, p. 100387, 2021, doi:10.1016/j.trip.2021.100387.

[25] A. Ibañez-Etxeberria, C. J. Gómez-Carrasco, O. Fontal, and S. García-Ceballos, "Virtual environments and augmented reality applied to heritage education. An evaluative study," *Appl. Sci.*, vol. 10, no. 7, 2020, doi:10.3390/app10072352.

[26] A. Balla *et al.*, "Augmented reality (AR) in minimally invasive surgery (MIS) training: where are we now in Italy? The Italian Society of Endoscopic Surgery (SICE) ARMIS survey.," *Updates Surg.*, vol. 75, no. 1, pp. 85–93, Jan. 2023, doi:10.1007/s13304-022-01383-6.

[27] Z. Q. Yang, D. Du, X. Y. Wei, and R. K. Y. Tong, "Augmented reality for stroke rehabilitation during COVID-19," *J. Neuroeng. Rehabil.*, vol. 19, no. 1, pp. 1–15, 2022, doi:10.1186/s12984-022-01100-9.

[28] M. F. Pereira, C. Prahm, J. Kolbenschlag, E. Oliveira, and N. F. Rodrigues, "Application of AR and VR in hand rehabilitation: A systematic review," *J. Biomed. Inform.*, vol. 111, p. 103584, Nov. 2020, doi:10.1016/J.JBI.2020.103584.

[29] D. S. Bhatti, N. U. Ain, and M. Fatima, "Occupational Hand-Related Injuries at a Major Tertiary Care Burn and Reconstructive Center in Pakistan," *Cureus*, vol. 12, no. 9, 2020, doi:10.7759/cureus.10444.

[30] A. Boschmann, D. Neuhaus, S. Vogt, C. Kaltschmidt, M. Platzner, and S. Dosen, "Immersive augmented reality system for the training of pattern classification control with a myoelectric prosthesis," *J. Neuroeng. Rehabil.*, vol. 18, no. 1, pp. 1–15, 2021, doi:10.1186/s12984-021-00822-6.

[31] J. A. Acevedo, "Application of robotic rehabilitation technologies in children with upper limb injury," vol. 49, no. 1, 2017.

[32] C. Moro, C. Phelps, P. Redmond, and Z. Stromberga, "HoloLens and mobile augmented reality in medical and health science education: A randomised controlled trial," *Br. J. Educ. Technol.*, vol. 52, no. 2, pp. 680–694, 2021, doi:10.1111/bjet.13049.

[33] M. D. Vles, N. C. O. Terng, K. Zijlstra, M. A. M. Mureau, and E. M. L. Corten, "Virtual and augmented reality for preoperative planning in plastic surgical procedures: A systematic review," *J. Plast. Reconstr. Aesthetic Surg.*, vol. 73, no. 11, pp. 1951–1959, 2020, doi:10.1016/j.bjps.2020.05.081.

[34] V. Mehta, Devraj, H. Chugh, and P. Banerjee, "Applications of Augmented Reality in Emerging Health Diagnostics: A Survey," in *2018 International Conference on Automation and Computational Engineering, ICACE 2018*, 2018, pp. 45–51.

[35] H. Sumdani, P. Aguilar-Salinas, M. J. Avila, S. R. Barber, and T. Dumont, "Utility of Augmented Reality and Virtual Reality in Spine Surgery: A Systematic Review of the Literature," *World Neurosurg.*, vol. 161, pp. e8–e17, 2022, doi:10.1016/j.wneu.2021.08.002.

[36] H. Ghaednia *et al.*, "Augmented and virtual reality in spine surgery, current applications and future potentials," *Spine J.*, vol. 21, no. 10, pp. 1617–1625, 2021, doi:10.1016/j.spinee.2021.03.018.

[37] C. Rodríguez-Abad, R. Rodríguez-González, A.-E. Martínez-Santos, and J.-D.-C. Fernández-de-la-Iglesia, "Effectiveness of augmented reality in learning about leg ulcer care: A quasi-experimental study in nursing students," *Nurse Educ. Today*, vol. 119, 2022, doi:10.1016/j.nedt.2022.105565.

[38] S. S. Menon, C. Holland, S. Farra, T. Wischgoll, and M. Stuber, "Augmented Reality in Nursing Education – A Pilot Study," *Clin. Simul. Nurs.*, vol. 65, pp. 57–61, 2022, doi:10.1016/j.ecns.2022.01.007.

[39] A. V. John, G. Abraham, and A. Alias, "Two-visit CAD/CAM milled dentures in the rehabilitation of edentulous arches: A case series," *J. Indian Prosthodont. Soc.*, vol. 19, no. 1, pp. 88–92, 2019, doi:10.4103/jips.jips.

[40] I. Al-Khaled, A. Al-Khaled, and H. Abutayyem, "Augmented reality in dentistry: Uses and applications in the digital era," *Edelweiss Appl. Sci. Technol.*, vol. 5, no. 1, pp. 25–32, 2021, doi:10.33805/2576-8484.191.

[41] Y. Zhou, P. Yoo, Y. Feng, A. Sankar, A. Sadr, and E. J. Seibel, "Towards AR-assisted visualisation and guidance for imaging of dental decay," *Healthc. Technol. Lett.*, vol. 6, no. 6, pp. 243–248, 2019, doi:10.1049/htl.2019.0082.

[42] C. Wang, C. Peng, Y. Hou, and M. Chen, "Retraction: Augmented Reality Research of Measuring X-Ray Dental Film Alveolar Bone Based on Computer Image Analysis System (Journal of Healthcare Engineering (2021) 2021 (5571862) DOI: 10.1155/2021/5571862)," *J. Healthc. Eng.*, vol. 2023, 2023, doi:10.1155/2023/9891705.

[43] Z. Haji, A. Arif, S. Jamal, and R. Ghafoor, "Augmented reality in clinical dental training and education.," *J. Pak. Med. Assoc.*, vol. 71(Suppl 1), no. 1, pp. S42–S48, Jan. 2021.

[44] N. Dzyuba, J. Jandu, J. Yates, and E. Kushnerev, "Virtual and augmented reality in dental education: The good, the bad and the better," *Eur. J. Dent. Educ.*, no. September, pp. 1–19, 2022, doi:10.1111/eje.12871.

[45] C. Innocente, L. Ulrich, S. Moos, and E. Vezzetti, "Augmented Reality: Mapping Methods and Tools for Enhancing the Human Role in Healthcare HMI," *Appl. Sci.*, vol. 12, no. 9, 2022, doi:10.3390/app12094295.

[46] M. R. Garfield and A. Dupont, "Augmented reality aided medical device design," *Front. Biomed. Devices, BIOMED - 2019 Des. Med. Devices Conf. DMD 2019*, pp. 16–18, 2019, doi:10.1115/DMD2019-3215.

[47] M. F. Pereira, C. Prahm, J. Kolbenschlag, E. Oliveira, and N. F. Rodrigues, "Application of AR and VR in hand rehabilitation: A systematic review," *J. Biomed. Inform.*, vol. 111, p. 103584, Nov. 2020, doi:10.1016/j.jbi.2020.103584.

[48] J. Ock, S. Moon, M. Kim, B. S. Ko, and N. Kim, "Evaluation of the accuracy of an augmented reality-based tumor-targeting guide for breast-conserving surgery," *Comput. Methods Programs Biomed.*, p. 108002, 2023, doi:https://doi.org/10.1016/j.cmpb.2023.108002.

[49] D. B. Douglas, J. M. Boone, E. Petricoin, L. Liotta, and E. Wilson, "Augmented Reality Imaging System: 3D Viewing of a Breast Cancer.," *J. Nat. Sci.*, vol. 2, no. 9, pp. 1–6, 2016.

[50] N. Costa *et al.*, "Augmented Reality-Assisted Ultrasound Breast Biopsy," *Sensors*, vol. 23, no. 4, pp. 1–14, 2023, doi:10.3390/s23041838.

[51] A. Newbury *et al.*, "Interventional oncology update," *Eur. J. Radiol. Open*, vol. 9, no. March, p. 100430, 2022, doi:10.1016/j.ejro.2022.100430.

[52] O. Hawajri, J. Lindberg, and S. Suominen, "Virtual Reality Exposure

Therapy as a Treatment Method Against Anxiety Disorders and Depression-A Structured Literature Review," *Issues Ment. Health Nurs.*, vol. 44, no. 4, pp. 245–269, 2023, doi:10.1080/01612840.2023.2190051.

[53] P. Lindner, W. Hamilton, A. Miloff, and P. Carlbring, "How to treat depression with low-intensity virtual reality interventions: Perspectives on translating cognitive behavioral techniques into the virtual reality modality and how to make anti-depressive use of virtual reality–unique experiences," *Front. Psychiatry*, vol. 10, no. OCT, pp. 1–6, 2019, doi:10.3389/fpsyt.2019.00792.

[54] N. Jingili, S. S. Oyelere, F. Ojwang, F. J. Agbo, and M. B. T. Nyström, "Virtual Reality for Addressing Depression and Anxiety: A Bibliometric Analysis.," *Int. J. Environ. Res. Public Health*, vol. 20, no. 9, Apr. 2023, doi:10.3390/ijerph20095621.

[55] J. Li, Z. Zheng, Y. Chai, X. Li, and X. Wei, "FaceMe: An agent-based social game using augmented reality for the emotional development of children with autism spectrum disorder," *Int. J. Hum. Comput. Stud.*, vol. 175, p. 103032, 2023, doi:https://doi.org/10.1016/j.ijhcs.2023.103032.

[56] S. K. Bhatt, N. I. De Leon, and A. Al-Jumaily, "Augmented reality game therapy for children with autism spectrum disorder," *Int. J. Smart Sens. Intell. Syst.*, vol. 7, no. 2, pp. 519–536, 2014, doi:10.21307/ijssis-2017-668.

[57] F. To-Miles, J. Mann, and L. Hung, "Facilitators and barriers to using virtual reality and augmented reality and its impact on social engagement in aged care settings: A scoping review protocol," *BMJ Open*, vol. 12, no. 8, 2022, doi:10.1136/bmjopen-2022-061722.

[58] Y. Chen *et al.*, "Extended Reality (XR) and telehealth interventions for children or adolescents with autism spectrum disorder: Systematic review of qualitative and quantitative studies," *Neurosci. Biobehav. Rev.*, vol. 138, 2022, doi:10.1016/j.neubiorev.2022.104683.

Juan David Parra Quintero. Born in Pitalito-Huila, Colombia on February 17, 1998. He graduated from the Institución Educativa Municipal Nacional and teaches full time in the industrial engineering program at the Fundación Universitaria Navarra. He received his mechanical engineering degree in 2020 from the Universidad Tecnológica de Pereira, in 2023 he obtained his M. Sc. degree in engineering from the Universidad de Antioquia, Colombia.
https://orcid.org/0000-0003-4544-0387

Carolina Alejandra Mueses Erazo. Born San Agustín-Huila, Colombia on September 4, 1999, Bachelor of the National Municipal Educational Institution. Student of XI semester of Medicine Universidad Pedagógica y Tecnológica de Colombia.
https://orcid.org/0000-0002-6019-8595