AUGMENTED REALITY AS A TECHNOLOGICAL RESOURCE FOR MECHANICAL ENGINEERING TEACHING

REALIDADE AUMENTADA COMO RECURSO TECNOLÓGICO PARA O ENSINO DE ENGENHARIA MECÂNICA

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Abstract. The contemporary school environment needs to be updated with technological innovations. Traditional whiteboards are replaced by projectors and digital whiteboards, which allows greater interaction with the content covered, thus enhancing the relationship between teaching and learning. The main objective of this research is to discuss the use of the technological resource called Augmented Reality (AR) aimed at teaching subjects related to Mechanical Engineering. This proposal aims to mitigate a difficulty, commonly found among students, related to the three-dimensional visualization of the elements represented in a two-dimensional way. The methodology adopted consists of a literature review with relevant works, in order to define the state of the art of the subject in question. As a result, the feasibility of using AR in the classroom in Mechanical Engineering disciplines is presented, requiring a previous qualification of the teacher responsible for the disciplines, as he will present himself as an intermediary in the process of knowledge construction by the student. The results and conclusions obtained affirm that the use of AR significantly enhances the teaching of this area, bringing a greater understanding of the contents related to Mechanical Engineering in a comprehensive way, highlighting the feasibility of use in the classroom.

Keywords: Engineering; Teaching; Learning; AR; Technology.

Resumo. O ambiente escolar contemporâneo precisa estar atualizado com as inovações tecnológicas. As lousas tradicionais são substituídas por projetores e lousas digitais, que permitem maior interação com o conteúdo abordado, potencializando a relação ensino-aprendizagem. O objetivo principal desta pesquisa é discutir a utilização do recurso tecnológico denominado Realidade Aumentada (RA) para o ensino de disciplinas relacionadas à Engenharia Mecânica. Esta proposta visa amenizar uma dificuldade, comumente encontrada entre os estudantes, relacionada à visualização tridimensional dos elementos representados de forma bidimensional. A metodologia adotada consiste em uma revisão bibliográfica com trabalhos relevantes, a fim de definir o estado da arte do assunto em questão. Como resultado, apresenta-se a viabilidade do uso da AR em sala de aula nas disciplinas de Engenharia Mecânica, exigindo uma qualificação prévia do professor responsável pelas disciplinas, uma vez que se apresentará como um intermediário no processo de construção do conhecimento pelo estudante. Os resultados e conclusões obtidos afirmam que o uso da AR melhora significativamente o ensino desta área, trazendo uma maior compreensão dos conteúdos relacionados à Engenharia Mecânica de forma integral, destacando a viabilidade do uso em sala de aula.

Palavras-chave: Engenharia; Ensino; Aprendizado; Realidade Aumentada; Tecnologia.

1. INTRODUCTION

Augmented Reality (AR) represents a technological resource capable of allowing greater interactivity with the built elements. In this way, through a smartphone with internet access, it is possible for the teacher and students to have access to AR functionalities, facilitating the understanding of the elements related to the disciplines. According to Mekni and Lemieux (2014), the acquisition of cell phones in a more accessible way by the population after the year 2010 made it possible to use AR's interactive resources also in the academic environment. In addition, Moran (2004) discusses that among the main complaints from students in universities is the format in which the subjects are taught, this highlights the need for changes that combine the insertion of technology in the teaching-learning process.

Although AR does not represent a new technology, with publications beginning in the 1960s, it is still not widely used in the classroom. Among the reasons is the lack of training of teachers on the tool. There are several texts on the efficiency of AR in teaching projects, such as Sá et al. (2007), which analyze the reduction of constructive errors, when planning the building with AR resources. Still, according to Lopes et al. (2019), it presents the development, among others, of interior projects and restoration of buildings with the help of AR.

However, a critical analysis of current literature reveals a significant gap in the systematic integration of AR in engineering education, particularly in Mechanical Engineering. Most existing studies address AR from a general pedagogical or technological perspective, lacking focused research that explores how AR can be aligned with specific learning outcomes in technical fields. There is also a scarcity of frameworks that guide educators in the practical implementation of AR within Mechanical Engineering curricula. This study contributes to addressing this gap by analyzing the state-of-the-art literature and proposing potential directions for meaningful application in this domain.

This research seeks to expand the current academic discussion by identifying how AR can enhance teaching effectiveness in Mechanical Engineering, a field that heavily relies on visual-spatial reasoning and complex system comprehension. By highlighting both the potential and the barriers, the study aims to guide educators and institutions toward strategic adoption of AR technologies, ultimately enriching student engagement and comprehension.

The advancement of this technology has encouraged the debate about its integration in the teaching and learning process. The academic training of mechanical engineering courses aims to obtain qualified professionals to face the inherent challenges of the job market, allied to this process is computational modeling, which acts as a strategy of great importance, allowing the improvement of the learning of concepts and the development of new knowledge.

Today's mechanical engineer must be able to propose solutions that are not only technically correct, but also have the ambition to consider problems in their entirety and as part of a chain of causes and effects of multiple dimensions. According to MEC (2010), failure to adapt to this scenario, through the training of professionals with such a profile, means delay in the development process.

The application of AR in Mechanical Engineering holds particular promise in disciplines such as Technical Drawing, Machine Elements, Fluid Mechanics, and Thermodynamics. These subjects often involve abstract concepts and complex visualizations that are traditionally taught using static 2D representations. AR enables dynamic 3D visualization, allowing students to interact with models, simulate behavior, and better grasp the spatial relationships and mechanics involved. In robotics and control systems, for instance, AR can be used to overlay system schematics onto real components, facilitating real-time diagnostics and comprehension.

Moreover, the hands-on nature of Mechanical Engineering demands experiential learning opportunities. AR can simulate laboratory environments and mechanical systems that may otherwise be inaccessible due to cost or safety constraints. It allows students to visualize force

vectors, torque, motion trajectories, and thermal behaviors in real time, thus making abstract concepts tangible.

In this way, among the various possible applications for use in disciplines focused on Mechanical Engineering, AR has the capacity to directly assist in learning. The objective of this work is to carry out bibliographic research on AR topics, in addition to collecting publications on the teaching of Mechanical Engineering and the application of AR in the teaching plans of subjects related to this branch of Engineering. The result of the analysis proves the importance of adopting this technological tool in the classroom, promoting the optimization of the learning of theoretical concepts and practical applications of mechanics.

2. LITERATURE REVIEW

In this section, the literature review of this research are organized as follows:

2.1: Augmented Reality (AR);
2.2: Teaching Mechanical Engineering;
2.3: Applications of AR in the teaching of subjects related to Mechanical Engineering.

After the bibliographic survey of the aforementioned themes, a spreadsheet was generated with information from the analyzed publications, encouraging the identification of common points of the subsections addressed.

2.1. Augmented Reality (AR)

AR represents an important tool for encouraging learning in several areas. The teacher would have a very accessible and easy-to-use technology available to develop the content with the students, through an approach focused on an active methodology, which indicates the student as a builder of his own knowledge, being assisted by the teacher.

Thus, according to Azuma (1997), AR consists of a system that complements the real environment with virtual elements, with a simultaneous interaction between them, highlighting the real objects. In addition to this explanation, Thornton et al. (2012), claim that this technology represents an emerging technology as a learning tool in the implementation of technology education curricula.

According to Romero and Hounsell (2018), unlike virtual reality, in which the user would be fully immersed in a virtual world, AR assumes the real world as a base, and there is an insertion of virtual elements to complement it.

Developed from the 1960s, according to Azuma (1997), AR has the possibility not only to improve educational processes but is also used in equipment assembly and maintenance services, according to Justimiano et al. (2021), training for aviation professionals (Figure 1), visualization of hydro sanitary installations (Figure 2), understanding of architectural and engineering elements (Figure 3), among others.

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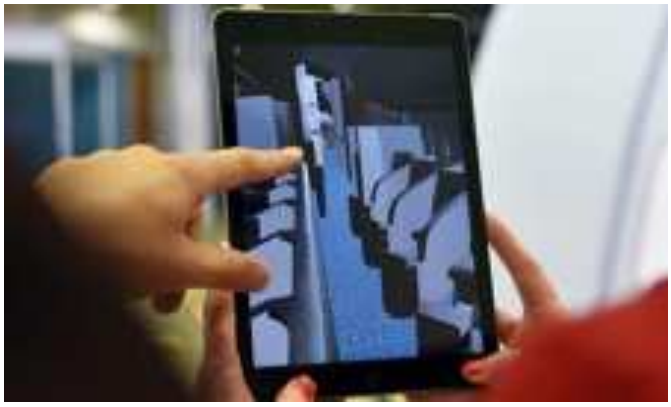


Figure 1. Training through AR for aviation professionals
Source: Pan Rotas (2018)



Figure 2. Visualization of the hydro sanitary facilities through the AR
Source: Archdaily (2019)

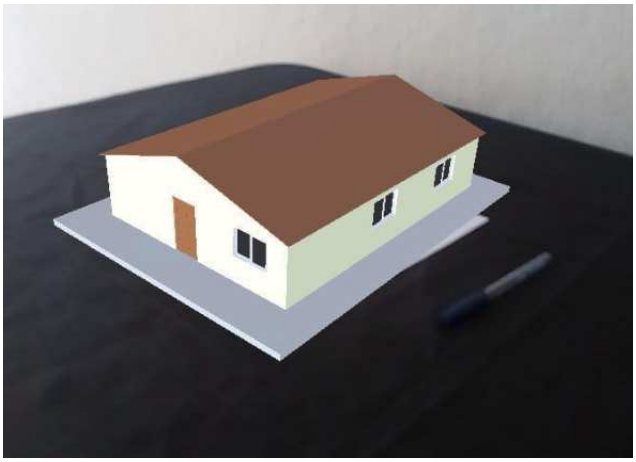


Figure 3. Visualization in AR of a building, aimed at architecture and engineering courses
Source: Authors (2023)

In addition to these possibilities of use, AR helps in the teaching and learning process of Topography, with the use of a sandbox combined with motion sensors, a digital projector and software (Moreira & Ruschel, 2015). In the field of geography, there are several studies using this tool, as indicated in Herpich et al. (2017), where it was possible to promote a case study with students through puzzles.

In view of these educational innovations, the potential achieved by this Information and Communication Technology (ICT) tool in the teaching and learning process becomes perceptible, as discussed in Lopes et al. (2019).

According to Leite (2020), in order to access AR resources, it is necessary to use a specific marker (identified in Figure 4). The smartphone, when detecting the marker image, projects the three-dimensional element, allowing visualization and interaction by the user. Regarding the difference between the concepts of AR and Virtual Reality (VR), it is important to note that VR seeks to transport the user to the virtual environment, whereas AR keeps the same user in their physical (real) environment and transports the virtual environment to the user's space, through some technological device (for example, a mobile device).

That is, AR is the action of including virtual objects (generally three-dimensional) produced digitally in a real environment using a technological resource. One of the advantages of AR that can be used in the teaching and learning process is its ability to provide three-dimensional visualization and be used in different smartphones based on the Android system widely used by students.

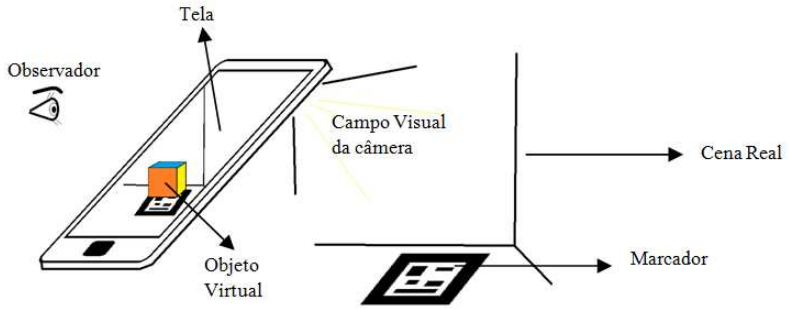


Figure 4. Representation of an AR system through smartphone
Source: ResearchGate (2017)

According to Herpich et al. (2020), the large volume of information made available through augmented reality affects the motivation of learning, giving the possibility to integrate transparently with the rest of the ICT resources generally used in an educational proposal. Also, when applied in the development of books and teaching materials, it allows introducing a new dimension that enriches the contents with interactive learning objects, which can also improve the understanding of the contents, promote a more active behavior of the student, increase the motivation and enhance the learning experience.

Furthermore, according to Pedrosa and Guimarães (2019), the distribution and use of the so-called "new technologies" have been the object of social and educational policies. Televisions, data-shows, electronic whiteboards, tablets and sound equipment are some of the artifacts available in educational institutions, usually accompanied by a discourse that determines the insertion of electronic artifacts and digital applications to improve the quality of teaching and innovation of the teaching-learning process.

In the field of Education, AR is presented, according to Lima et al. (2020), due to its versatility, the use of AR with emerging technologies aimed at the educational area, such as mobile devices, and educational games, among others, is increasing. AR emerges as a perspective with the potential to complement educational applications, since it makes it possible to explore its virtual resources with an educational bias, adding to these educational solutions the scale presentation of three-dimensional virtual elements, among other features. Table 1 below shows the list of publications addressed in the present work on AR:

Table 1. List of publications studied on AR

Title	Type	Year	Authors	Description	Applicability in Mechanical Engineering
Augmented reality as a visual and spatial learning tool in technology education	Article	2012	Thornton Ernst; Clark	The study focuses on the application of augmented reality (AR) in technology and engineering education, highlighting its potential to facilitate visual representations, spatial skills development and to engage students interactively and realistically in the learning process.	This study shows that AR can improve the teaching of design, assembly and analysis of mechanical components, providing three-dimensional and interactive visualizations that increase spatial understanding and technical reasoning in Mechanical Engineering.
Introdução à Realidade Virtual e Aumentada	Book	2018	Tori; Hounsell (org.).	This book offers an in-depth introduction to the concepts, technologies and applications of Virtual and Augmented Reality, covering everything from its fundamentals to its practical implementations, including technical and theoretical aspects. It aims to present the scope of the area, its possibilities and developments up to 2018.	The study on Virtual and Augmented Reality in Mechanical Engineering is applicable to the simulation, maintenance, training and optimization of industrial processes, promoting greater precision, safety and efficiency in the development of projects and operations.
Sistema de Realidade Aumentada para o Ensino e Treinamento de Pessoas Quanto a Execução de Serviços de Montagem e Manutenção de Equipamentos	Article	2021	Justimiano et al.	The article presents an Augmented Reality system that offers remote support for training and equipment maintenance, allowing guidance for non-specialized users and reducing on-site risks during the COVID-19 pandemic.	The text highlights the application of Augmented Reality in the maintenance of machines and equipment, including examples such as boilers, digital printers and automotive assembly lines. These technologies assist in the execution of complex procedures, making support more efficient in mechanical engineering.

Realidade aumentada na visualização de soluções do projeto de arquitetura	Article	2015	Moreira; Ruschel	The article investigates visualization strategies for architectural solutions using Augmented Reality, comparing mobile and projected devices, to improve the discussion and understanding of proposals in social housing projects.	The text mentions that the application of Augmented Reality has been used as a learning tool in engineering courses, demonstrating its viability in education and technical training. In addition, studies indicate its potential in participatory processes during the development of architectural projects and in the validation of technological solutions in civil construction.
Realidade aumentada em geografia: uma atividade de orientação no ensino fundamental	Article	2017	Herpich et al.	The article presents an orientation activity in Geography that uses augmented reality and mobile devices to facilitate teaching and learning, promoting the integration between theory and practice in elementary education.	Although the text focuses on teaching Geography, it has examples in the field of Mechanical Engineering.
Inovações educacionais com o uso da realidade aumentada: uma revisão sistemática	Article	2019	Lopes et al.	This article performs a systematic review to analyze how Augmented Reality (AR) is being applied in education, identifying its contributions to teaching and learning, as well as the main challenges and factors that influence its effective use. Its focus is to understand the innovative practices and the impact of AR in the educational context.	The article highlights the use of Augmented Reality in teaching Engineering, including Mechanical Engineering, through the creation of books and 3D visualization environments to show machinery and equipment, promoting greater safety by reducing the risk of accidents in the workplace. In addition, AR helps novice designers generate ideas and formulate more effective design strategies, expanding practical knowledge.
Aplicativos de realidade virtual e realidade aumentada	Article	2020	Leite	O artigo analisa aplicativos de realidade virtual e aumentada disponíveis	This article does not directly address the application of virtual and augmented reality

para o ensino de Química				para dispositivos móveis que podem ser utilizados no ensino de Química, destacando suas possibilidades pedagógicas e limitações para professores e estudantes. Seu foco está na potencialidade dessas tecnologias para facilitar a visualização e compreensão de conceitos químicos complexos.	applications in teaching Chemistry for Mechanical Engineering, focusing mainly on high school content. However, the three-dimensional and interactive visualization of chemical concepts can contribute to the training of students in technological areas, including Engineering, by facilitating the understanding of complex chemical structures and reactions.
Atividade Educacional utilizando Realidade Aumentada para o ensino de Física no Ensino Superior	Article	2020	Herpich; Lima; Nunes	The article focuses on the evaluation of an educational approach with an augmented reality application for mobile devices in Physics teaching, analyzing the dimensions of usability, engagement, motivation and learning of university students.	The text presents an educational activity using an augmented reality application to simulate the "Combustion Engine", contextualizing physical concepts relevant to the Mechanical Engineering course. This simulation was used in meetings dedicated to understanding the atomic spectrum and electromagnetic radiation, facilitating practical learning.
Realidade Virtual e Realidade Aumentada: refletindo sobre os usos e benefícios na educação	Article	2019	Pedrosa; Zappala-Guimarães	The article focuses on the critical analysis of the use of Virtual Reality and Augmented Reality in education, examining their concepts, benefits, limitations and motivations to enhance the teaching-learning process in contemporary society.	
Uma Revisão sistemática da literatura sobre atividades	Article	2021	Lima et al.	The article analyzes the applicability of Augmented Reality in the teaching of Natural	The article does not directly address the application of Augmented Reality in

educacionais de realidade aumentada do ensino de ciências da natureza				Sciences through a systematic review of the literature, identifying contents covered, platforms used and the benefits of this technology in the teaching-learning process.	mechanical engineering, focusing mainly on the teaching of Natural Sciences. However, it mentions the use of interactive technologies and software that can be applied in areas such as physics and exact sciences, which are the basis for engineering.

Source: Authors (2024)

Therefore, it is possible to develop several AR systems as an auxiliary tool in different areas of knowledge. As the objective of this research is to verify the optimization capacity of this technology for the teaching of Mechanical Engineering, it would thus represent a powerful ally.

2.2. Teaching Mechanical Engineering

The training of a Mechanical Engineering professional is notably complex. Tracing a vast field of knowledge, students and professors visit areas of science and technology, composing throughout the course the profile necessary for the mechanical engineering professional. Over decades, teaching methods have been improved, feeling the effect of society's cultural and technological development. So many improvements proved necessary in that area, since the mechanical engineer needs a range of knowledge to perform his functions.

For example, in the classroom, the study of disciplines focused on Mechanical Engineering, such as gear design, requires prior knowledge of other disciplines, such as Solid Mechanics, in addition to the previous base of Machine Elements. The process, well divided into several steps, involves knowledge, several calculations of equations of different complexities, unit conversions, and important considerations that affect variables, in addition to, normally, due to so many steps, it takes a considerable time for the student to complete a case by complete. In other words, the practicality of learning in the classroom, or outside it, demands a lot of effort and time from the student.

Focusing on the subjects, according to Rocha et al. (2019), it is necessary to value the teaching of machining in mechanical engineering courses, approaching the subject in a sustainable way in the manufacture of didactic material. Replacing traditional cutting tools with instruments made of miriti, the teacher conveys to the student the idea of reducing the total cost, generating greater accessibility without losing the quality of the tools.

When it comes to the use of concept maps in the disciplines of the Mechanical Engineering course, Krummenauer and Darroz (2019) state that it is possible to verify an advance in the significant learning of students, through assimilation and investigation. In addition, Krummenauer and Costa (2009) prove the feasibility and potential of concept maps, developing new ways of learning.

In the field of evaluation, according to Freitas et al. (2021), they conduct research on a proposal for formative, continuous and diagnostic analysis applied directly to the Mechanical Engineering higher education course. The authors state that traditional assessment limits the student's control of learning, not understanding the difference in students' comprehension rhythms. In the proposal presented by the authors, resources from active methodologies are

used to make the Mechanical Engineering student the center of their learning process, making the teacher an intermediary. Table 2 below shows the list of publications addressed in this work on the teaching of Mechanical Engineering:

Table 2. List of publications addressed on the teaching of Mechanical Engineering

Title	Type	Year	Authors	Description	Applicability in Mechanical Engineering
Uso sustentável da palmeira de miriti como matéria prima e ferramenta didática no ensino/aprendizagem na disciplina de usinagem de materiais na engenharia mecânica	Article	2019	Rocha et al.	The article proposes the sustainable use of miriti as a raw material for the manufacture of teaching tools in machining in mechanical engineering, facilitating the understanding of cutting angles and reducing costs and logistical difficulties in academic training.	In teaching Mechanical Engineering, the selection of cutting tools is essential, considering factors such as machined material and type of operation. The use of miriti makes it possible to manufacture teaching tools that facilitate practical learning of cutting technology, which is important for machining and turning.
Avaliação através de mapas conceituais em uma disciplina de física no curso de Engenharia Mecânica	Article	2019	Krummenauer ; Darroz	The article presents an experience of using conceptual maps as a tool for assessing significant learning in the electrostatics unit in a Physics for Mechanical Engineering discipline, highlighting the conceptual progress and hierarchical organization of students.	The teaching proposal was developed with a class of 18 students from the Mechanical Engineering course, in the 2019/1 semester, in a General Physics discipline, aiming to evaluate the mastery and the relationship of concepts in the thematic unit of electrostatics. The use of concept maps allowed us to identify how students organize the content in the cognitive structure, contributing to teaching in Engineering.

Mapas conceituais como instrumentos de avaliação na Educação de Jovens e Adultos	Article	2009	Krummenauer ; Costa	The article reports the use of conceptual maps as an assessment tool to overcome mathematical and conceptual difficulties in Physics in Youth and Adult Education, highlighting advances in the organization and hierarchy of concepts by students.	The article focuses on the use of this tool for teaching Physics in a Youth and Adult Education (EJA) class. Therefore, there is no direct mention of Mechanical Engineering in the content presented.
Relações entre metodologia ativa, avaliação formativa e aprendizagem discente no curso de engenharia mecânica	Article	2021	Freitas; Fontana; Zatti	The article investigates the relationship between active methodologies and formative assessment in teaching the subject Fundamentals of Automotive Mechanical Engineering, highlighting how this combination increased learning, reduced repetition and dropout, and highlighted the importance of interdisciplinarity and contextualization of content.	The action research was carried out in the Fundamentals of Automotive Mechanical Engineering discipline, in the first period of the Mechanical Engineering course, during the 2019 academic semester, with 34 students. In this application, active methodologies and formative assessment were used to address failure, dropout and specific learning difficulties of the course.

Source: Authors (2024)

Therefore, for the teaching of Mechanical Engineering, in which the focus is on the design, development, assembly and maintenance of machines and equipment, the teacher needs to seek, in addition to new theoretical and practical knowledge, pedagogical strategies so that the student can build more effective learning. It is also necessary to adopt new technologies to optimize the entire process. Following this reflection, the following section will address the main uses of AR in the field of Mechanical Engineering.

2.3. Applications of AR in the teaching of subjects focused on Mechanical Engineering

The AR, due to its remarkable potential for application in the different areas of knowledge, assumes a greater capacity for use in the different disciplines focused on Mechanical Engineering. The interactivity and three-dimensional visualization allow the student in this area to understand the mechanical elements and the working relationship of the whole set. In this section, the main applications of AR in the aforementioned topic will be presented, aiming at understanding the learning potential provided by this technology.

In disciplines related to Technical Drawing, Aliev et al. (2017) state that this discipline is easier to learn, since the three-dimensional visualization complements the understanding generated by orthogonal views and also by perspectives. Thus, for mechanical engineering

students, through software such as Unity and Vuforia, there is the possibility of exploring the possibilities of teaching and learning through interactivity. Figure 5 shows an example of this use:



Figure 5. Three-dimensional projection in AR of a Technical Drawing element
Source: Archdaily (2023)

In addition, the study by Gutierrez and Fernandéz (2014) aimed to develop and apply an AR-supported book. Its application proved that Mechanical Engineering students who used the book with AR had greater motivation and better academic performance than those who did not use the technology. Through the markers, it was possible to access the AR resources and, consequently, view and interact with the content covered.

Macedo et al. (2021) address the use of a bar-shaped magnetic field through the resources provided by AR. Five students from the mechanical engineering course participated in the research, who had the opportunity to interact with the virtual object in the three dimensions of the magnetic field. It was concluded that the AR tools potentiated the teaching and learning of the discipline.

Diniz (2012) develops research on robotic devices with the AR interface. At work, through Computer Graphics techniques, an experiment was built of a robotic arm that, being activated naturally, is able to move in the AR environment. For the teaching of Mechanical Engineering, it represents an important advance for the understanding of the mechanical system allied to robotics. Table 3 below provides information on the texts covered in this section:

Table 3. Survey of publications addressed in section 2.3

Title	Type	Year	Authors	Description	Applicability in Mechanical Engineering
3D Augmented Reality Software Solution for Mechanical Engineering Education	Article	2017	Aliev et al.	The document explores the use of augmented reality technology in the teaching and training of mechanical engineers. It presents the development of software designed to track augmented reality markers, facilitating learning in the field of mechanical engineering. In addition, it proposes a methodology for creating	One of the applications of augmented reality in mechanical engineering highlighted in the text is the creation of interactive teaching materials. Using specific software, students and professionals in the field can view three-dimensional models of cutting tools, measuring instruments, and specialized equipment.

				a textbook, incorporating three-dimensional models of cutting tools, measuring instruments and specialized equipment, all accessible through augmented reality.	This facilitates the understanding of concepts and practical learning, making teaching more dynamic and intuitive. In addition, this approach improves the training of engineers by providing an immersive experience, allowing detailed analysis of components and their functionalities before physical handling.
Applying Augmented Reality in engineering education to improve academic performance & student motivation	Article	2014	Gutiérrez; Fernández	The study examines how Augmented Reality (AR) enhances academic performance and student motivation in engineering education. A group using AR-based didactic materials outperformed a control group relying on traditional notes. The results indicate that AR improves learning efficiency and engagement among students.	Augmented Reality (AR) in mechanical engineering can be applied to teaching complex concepts through interactive didactic materials. In the study, this technology was used to help students understand standardized mechanical elements, providing a more visual and dynamic experience. This approach enhances learning by allowing detailed exploration of three-dimensional components, increasing knowledge retention and student motivation.
Ensino do Campo Magnético de um Ímã em Forma de Barra Utilizando Recursos de Realidade Aumentada	Article	2021	Macedo; Biazus; Fernandes	The article focuses on the development and use of a Learning Object in an Augmented Reality environment for teaching the magnetic field of a bar magnet, providing three-dimensional visualization and interaction to facilitate the understanding of magnetic phenomena.	Mechanical Engineering students participated in the experiment using the Augmented Reality Learning Object to visualize the magnetic field, considering the study of electromagnetic physical phenomena fundamental to their training. This tool helped in the understanding of concepts invisible in traditional teaching, benefiting future mechanical engineers.
Acionamento de dispositivos robóticos através de	Thesis (Master's degree)	2012	Diniz	The article develops a natural interface based on human arm gestures for the remote activation of a	In mechanical engineering, the development of robotic systems and their operating strategies is a

interface natural em realidade aumentada				robotic arm in an augmented reality environment, using computer vision with the Kinect™ sensor and network communication for remote control of the device.	challenge due to the complexity of the movements involved, requiring intuitive interfaces to facilitate their control. The use of natural interfaces, such as gesture-based ones, can accelerate the learning and operation of these complex systems. Thus, the application of natural interfaces in augmented reality environments assists in the efficient remote operation of mechanical robotic devices.

Source: Authors (2024)

Thus, analyzing the applications of AR in the field of Mechanical Engineering, when extending the reflection to teaching, it is noted that there is a great potential for optimizing the learning of subjects related to the area. It is up to the teacher to qualify, so that it is possible to encourage the use of this technology throughout the course. In this way, students will have a greater ability to understand through interactivity.

3. MATERIALS AND METHODS

This study employed a qualitative approach through a structured literature review, aimed at identifying, selecting, and analyzing existing academic contributions on the use of Augmented Reality (AR) in the teaching of Mechanical Engineering. The objective was to map the current state of the art, highlight trends, and assess the feasibility and pedagogical impact of AR technologies in the mechanical engineering curriculum.

The methodological procedure was based on a narrative and systematic bibliographic review, conducted between January and October 2024. The review sought to answer the following research question: "How has Augmented Reality been applied as an educational tool in the context of Mechanical Engineering, and what benefits or limitations are evidenced in literature?"

The data collection process was carried out using academic databases and repositories such as Scopus, Web of Science, Google Scholar, SciELO, and ERIC. Search terms included combinations of the following descriptors: “Augmented Reality,” “Mechanical Engineering,” “Engineering Education,” “AR in teaching,” “Technology in education,” and “3D visualization.” Boolean operators (AND, OR) were used to refine the searches and improve relevance.

To ensure scientific rigor, the following inclusion criteria were adopted: Publications dated from 2007 to 2024; Peer-reviewed articles, theses, and book chapters available in full text; Studies addressing the application of AR in educational contexts, particularly in Engineering; Texts written in English, Portuguese, or Spanish; Works demonstrating empirical data, theoretical analysis, or didactic proposals related to AR in Mechanical Engineering or STEM disciplines with evident applicability to Mechanical Engineering.

Publications were excluded based on the following criteria: Duplicates found in more than one database; Studies focusing exclusively on Virtual Reality (VR) without any reference to AR; Works that addressed AR only in entertainment, marketing, or unrelated industries;

Articles with insufficient methodological detail or lacking academic/scientific rigor; Educational interventions not associated with engineering or technological disciplines.

Selected studies were organized in a structured spreadsheet including title, year, authors, type of publication, main contributions, and specific applicability to Mechanical Engineering. Each publication was critically read and coded according to its relevance to the research objectives. Categorization followed three thematic axes: General concepts and evolution of AR, Pedagogical approaches in Mechanical Engineering, and Specific applications of AR in engineering disciplines.

A qualitative synthesis was carried out to identify patterns, trends, and gaps in literature. The analysis focused on extracting evidence of how AR tools have enhanced learning outcomes, student engagement, conceptual understanding, and the overall quality of engineering education. Comparative analyses were also performed between traditional methods and AR-supported strategies, when data were available.

4. RESULTS

As a result of the literature review, it is noted that there is great potential for the use of AR in the teaching of subjects related to Mechanical Engineering. Considered one of the tools inserted in the field of the metaverse (a new layer of reality that integrates the real and virtual worlds), AR brings in its concept of the partial interaction between the digitally created universe and the real world. Through the analysis of the works discussed in the previous section, it is concluded that this technology is capable of replacing the infrastructure of a laboratory, generating a more affordable investment for the school institution.

The professor of Mechanical Engineering subjects, in turn, would have the possibility to analyze with the students and in a three-dimensional way the systems and functions of machine parts in general. The AR, according to the analyzed bibliography, requiring only the use of a smartphone with internet access, encourages the student to use the cell phone as an ally for their learning process. There is a great discussion about the importance of cell phones in the classroom, since most students have some kind of device. Thus, AR presents itself as an important didactic tool capable of optimizing the teaching of these related subjects.

When it comes to the teaching of Mechanical Engineering, when analyzing the bibliographic material presented in the previous section, it is noted that, taking into account the complexity of the training of the mechanical engineer, not only technological training is necessary, but also cultural and environmental responsibility. The teaching of subjects focused on this area must overcome the traditional model, which treats the teacher as a full holder of knowledge and, still, considered unquestionable, in addition to the student being considered passive and absorbing concepts, not reflecting on the content. It is necessary, therefore, that the premises of active methodologies be adopted in the teaching of Mechanical Engineering, in the sense of making the student an agent that builds his own knowledge.

As a way to make the student active, the literature review carried out in the previous section proposes the use of AR as a viable tool for the disciplines of the Mechanical Engineering course. One of the examples discussed in the present work was the use of AR in the discipline of Technical Drawing, which allowed a greater understanding of the views and perspectives by the students, enhancing the level of understanding of the content. AR assumes, when analyzing the publications addressed in the research, a great potential and with several possibilities of application in the teaching of the field of Mechanical Engineering, through a notably affordable cost.

5. CONCLUSION

The bibliographic review carried out in relevant publications on the topics of Augmented Reality (AR), the teaching of Mechanical Engineering, and the applications of AR in the teaching of subjects related to this branch of Engineering confirmed the importance and ease of use of this technology in academic settings. Various approaches to implementing AR in education support the construction of knowledge by students, positioning the teacher as a mediator between content and learner.

Observing the broad scope of subjects within Mechanical Engineering programs, it is evident that students often face learning challenges due to traditional teaching methods, where instruction is centered on blackboard use and static texts. As a result, students assume a passive role in the learning process, with limited opportunities for conceptual reflection, which ultimately affects their academic and professional development.

This study, therefore, aimed to reflect on the diversity of content in Mechanical Engineering courses and to highlight AR as a viable technological alternative to support the understanding of complex, spatial, and system-based concepts essential to the training of future mechanical engineers. It also emphasized the potential of mobile phones as interactive tools for enhancing engagement through real-time, three-dimensional content exploration, enabling a closer connection between theoretical knowledge and professional practice.

However, this study is not without limitations. Being based exclusively on a literature review, it lacks empirical validation through practical implementation or case studies that directly measure learning outcomes, user experience, or long-term academic performance. Additionally, the rapid evolution of AR technologies may render some of the findings time-sensitive, requiring continuous updates to remain relevant. The lack of standardized pedagogical frameworks for integrating AR into Mechanical Engineering curricula also presents a challenge for its systematic adoption.

Future research could address these gaps by conducting experimental or quasi-experimental studies to evaluate the effectiveness of AR in specific subjects such as Technical Drawing, Fluid Mechanics, or Thermodynamics. Investigating the development of low-cost AR tools adapted to institutional realities, as well as teacher training programs that focus on technological and pedagogical integration, also represents promising directions. Moreover, interdisciplinary studies involving cognitive psychology, instructional design, and engineering education could further illuminate the cognitive impact of AR on spatial reasoning and problem-solving abilities.

In practical terms, the implications of this study suggest that the integration of AR into Mechanical Engineering education not only enhances conceptual understanding but also contributes to more student-centered and immersive learning experiences. Educational institutions and curriculum designers should consider investing in AR infrastructure and training initiatives to support the pedagogical shift toward active, technology-assisted methodologies.

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